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UNIVERSITIES, RESEARCH AND BRAIN WASTE

By J. C. Fields, Ph.D., F.R.S.

To the Members of the Royal Canadian Institute

Ladies and Gentlemen:

It is my desire first of all to thank you for the honour which you have conferred on me by electing me your President for the year now beginning. The two years past have been prosperous ones under the

ERRATA.

1. Read *have* instead of *base* p. 24, line 10.
2. In place of *Dendronotus ruber* read *Dendronotus rufus*, p. 147.
3. Throughout the article on Nudibranchiate Mollusca (p. 147) in place of *Chioraeridae* read *Chioraera*.
4. In "Explanation of Plates," pages 207-9 read *Plates VII-XI*.

[illegible] thoughts to the fund already accumulated. These are the so-called research workers. Men of research inclination there have been in all countries and in all periods. In recent times, however, the number has increased greatly. Certain universities in America, and a large proportion of those in Europe, regard it as one of their functions to prepare men to do research. Many of the European universities regard it as their chief function.

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Ladies and Gentlemen:

It is my desire first of all to thank you for the honour which you have conferred on me by electing me your President for the year now beginning. The two years past have been prosperous ones under the Presidency of Dr. J. Murray Clark. Many new members have joined and the attendance at the meetings has appreciably increased. The Institute has carried on its propaganda for research both in regard to its application to industry and on the purely scientific side. In its campaign it has been aided by a succession of eminent lecturers from the United States. The activities of the Institute will continue to be directed by the same policy as hitherto and I may say that arrangements have been made for a group of exceptionally able men to lecture under its auspices in Toronto during the coming winter.

With your permission I shall now turn my attention to the consideration of the subject which I have selected for my address this evening—"Universities, Research and Brain Waste."

Whatever the undeveloped resources of a country may be the greatest of all its resources is the brain of the people and more especially the brain of the exceptionally gifted. Other resources in fact are made available only by combination with this primary resource. The wealth of the race consists of the thoughts of a limited number of men accumulated through the generations. By means of these thoughts, or certain of them, we are able to reproduce things. It takes no great mental effort to realize that of all the material products of man's hands which existed fifty years ago, that which persists to-day is negligible.

There exists a body of men whose function it is to increase the wealth of the race, to add new thoughts to the fund already accumulated. These are the so-called research workers. Men of research inclination there have been in all countries and in all periods. In recent times, however, the number has increased greatly. Certain universities in America, and a large proportion of those in Europe, regard it as one of their functions to prepare men to do research. Many of the European universities regard it as their chief function.

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The research workers are makers of modern history as no other body of men are. The difference between the conditions under which our forefathers lived three hundred years ago and those under which we live to-day is due to the research workers. The layman little realizes what an influence individual men among these research workers exercise upon his daily life. In ordinary conversation the name of Shakespeare is heard more frequently than that of Newton and students of the great dramatist will be surprised to be told that Shakespeare as a factor in determining their lives is a bagatelle compared to Newton. The thought of the great scientist, as a matter of fact, permeates our civilization and can be traced distinctly in a multitude of conditions which surround our every-day life. To justify our statement, it suffices to refer briefly to Newton's discoveries of the calculus and the law of gravitation. The calculus is the basis of the greater part of higher mathematical analysis. It is the most powerful of all instruments in handling geometrical problems and it has opened up new territories in geometry which are all its own. What I want more particularly here to refer to, however, is the role which the calculus plays in connection with physical phenomena. Its aid is invoked in questions which relate to motion, light, heat, electricity. The principles of dynamics are formulated in terms of its notation. Unfortunately it has had a share in the development of modern artillery, for the theory of projectiles is an application of the calculus to the law of gravitation. It has had its place in the advances which have brought us the electric light, the trolley, the power house, telegraphy and telephony, both with and without wire. When we read the despatches and cablegrams in our morning paper we do not pause to remind ourselves that the thought of Newton is one of the factors which has made this possible. No more does it occur to the baseball enthusiast that he is under any debt to Newton when he stands before the newspaper office down town and scans the latest baseball bulletin.

Transportation by sea, by land and by air, has much for which to thank Newton. The calculus had nothing to do with the invention of the steam engine by James Watt. It has, however, done important service during the last half century or more in handling problems relating to steam engines and turbines where fundamental principles have been involved. It has had its effect on naval construction. It is involved in the general question of the relation between shape, power and speed in connection with a vessel. It is essential to the study of the strains and stresses in a ship's members. Navigation, too, depends on astronomical data the obtaining of which involves the use of the calculus. Our clocks and watches are regulated by data so obtained. It has had its share in the development of the automobile engine. It proves itself

useful in problems connected with hydraulic elevators. It played a fundamental role in solving the initial difficulties connected with flight, and later on it was an essential instrument in solving the problem of stability in relation to aeroplanes. It renders valuable assistance in connection with the finding of necessary data for the putting up of large steel bridges and for erecting other engineering structures. Physical chemistry makes extensive use of the formulae of the calculus. The physiologist, too, when he is confronted with problems in surface tension is forced to call in its aid.

The same godlike instrument enables the astronomer to follow the earth and the planets in their courses about the sun and to keep track of the moon in its more devious path around the earth as the latter whirls about the sun. It renders it possible for him to measure the combined and varying tugs of the sun and moon on the waters of the earth and with its formulae he traces the paths of the particles of water that go to make up the tides as they travel across the oceans of the earth. By the aid of this instrument applied to the solar system, on the assumption that it is regulated by the law of gravitation, Adams and Leverrier, led thereto by certain inequalities noted in the motion of the planet Uranus, deduced the existence and location of the planet Neptune and foretold its mass and orbit.

Clerk Maxwell it was who formulated the theory of electricity and magnetism in terms of the calculus. Hertz devised the experiment which verified the existence of certain waves in the ether predicted by Maxwell from his theory and Marconi utilized these waves for wireless telegraphy. In later times we have become familiar with X-rays, radio-activity and the theory of electrons. The physicist studies the relative positions of the atoms in a molecule and going beyond distributes the atom itself into electrons. He tells us wonderful stories about the energy locked up in an atom and Sir Oliver Lodge informs us that if this atomic energy were only available a ton of matter day by day would suffice to supply the needs of Great Britain. Going over from the infinitely small to the infinitely great that eminent Dutch astronomer and hardy generalizer, Kapteyn, has launched a scheme to study the structure of the universe. His nearest material is over 25 trillion miles away but his scheme is under way and he is steadily accumulating his data. At some stage in the development of all the branches of physical science here referred to Newton's thought has played a role and the calculus has proved itself a helpful instrument in regions undreamed of by its discoverer.

In what precedes I have touched on the physical sciences and the application of the calculus to them. I have mentioned but a few

among the many great names associated with the development of these sciences. I have wished in a few words to do the impossible, to suggest to the layman by an illustration something of the reach and importance of research, to indicate how the work of one research man connects up with that of another and to shadow forth how intimately the life work of some great thinker may be related to our daily life and activities without our being conscious of the fact. Newton himself, it may be pointed out, was not such an unconditioned being that his work was independent of that of the workers who preceded him. The discovery of the calculus was already a foregone conclusion after Descartes had invented analytical geometry. In the hands of a lesser genius, however, its scope would not have been as fully appreciated and immediate results would have been more meagre. I wish that I could convey briefly to the laymen in my audience some conception of the nature of the calculus but this is not within my power to do. That will perhaps not be surprising in view of the fact that a hundred lectures are devoted to introducing the honours students in mathematics and physics to the subject in their second year and that a considerable portion of their time in their third and fourth years is utilized in increasing their appreciation of its scope and application.

In the foregoing I have said nothing about the immense contributions of chemistry to the health, wealth and comfort of mankind. I have not referred to the debt we owe to biology, botany, bacteriology, geology, and various other branches of science. I have pointed out the successive dependence of one man's work on another's. I would draw attention also to the simultaneous co-operative character of scientific work. For hundreds of research workers in different parts of the world are at the same time busied on the same problems or on related problems. They keep in touch with one another's work principally through highly specialized journals which the layman never sees. In these journals as a rule the results of their investigations are published. To expedite matters it has been found necessary to devise certain aids. One of these is the International Catalogue of Scientific Literature which, before the war, appeared annually in seventeen volumes, each volume corresponding to a separate branch of science. Besides an alphabetical list of authors each volume contains an elaborately classified subject index. This, however, in view of the mass of material being turned out, does not suffice for the needs of the research worker who wants speedy orientation with regard to everything which may have a bearing on his own special line of work. For this something more than a mere classification of titles is needed. Some further indication as to the contents of an article is necessary. The need here referred to is

more or less satisfactorily cared for in different branches of science. In physics and electrical engineering, for example, we have what are called "Science Abstracts".

The need of orientation will be better realized by the layman when he is told that the number of titles listed in the seventeen volumes of the International Catalogue for the year 1912 was 67,926. The great bulk of the literature here referred to is of research character and its authors number up in the tens of thousands. The individuals in this army of investigators vary greatly in ability. Many of them are handicapped by the conditions under which they have to work. The products of their efforts are, of course, very unequal. In the aggregate, however, the importance of the activities of the army of research workers to the welfare of the nations can hardly be overestimated. How many of the nations, how many of the individuals who go to make up the nations, realize this fact? How many of our own people appreciate it adequately?

That does not exist which I do not see is the most prevalent and most disastrous of all fallacies. Every day men in high places act on this fallacy. It shapes important policies and determines great issues. It came very near being the undoing of Great Britain when the opening of the war found her scientifically unprepared, for her statesmen in taking counsel had been accustomed to leaving out of account science which, as it proved, was the most important factor in the situation. It is my own conviction and that of all scientists with whom I have discussed the matter that the modern research movement is the greatest intellectual movement in the history of the human race. How many Governments act as if this conviction had taken hold on them? In how many of the universities on this continent have those in authority seen the vision?

The natural home of research is in the universities. There most of the fundamental discoveries in science have been made in the recent past. Let us hope that this may continue to be the case in the future. The highest functions of a university are on the one hand to provide place and opportunity for the research worker to carry on and make his discoveries and on the other hand to train young men of selected ability to use their creative faculties. This is more fully appreciated in certain European countries than in America.

In Germany, at least before the war, no man was appointed to a university staff who had not proved himself to be intellectually productive. Once appointed he could lecture as little or as much as he pleased. He could devote practically all his time to research if he was so inclined. He was relieved of financial worry. He did not need to preoccupy himself with what, under certain eventualities, would become

of his wife and family. Everything was provided for in advance so that, with a mind at ease, he could concentrate all his powers on his science. On the instructional side the German university had particularly in mind the student of exceptional ability. It put no obstacle in the way of admitting others. It was not a difficult matter to obtain a degree. The arrangements, however, were made with a view to the needs of the more highly gifted. These were trained to be research workers and those who distinguished themselves most in research were the ones who received preferment later on. The intellectually productive men then enjoyed a certain prestige in Germany before the war. This was overshadowed, however, by the factitious prestige attached to the military uniform, and we know how the war-mad militarists of Potsdam prostituted German science and purposed by its aid to subjugate the rest of the world.

In France perhaps more than in any other country is intellectual achievement honoured. An intellectual aristocracy, according to Professor Le Chatelier, is essential to the French democracy. This means that intellect is trained to the service of the State. In peace times membership in one of the five academies which constitute the Institut de France, a purely intellectual distinction, is the highest honour to which a Frenchman can aspire. The Institut, it may be noted, through its Academies disposes of considerable sums as rewards for notable intellectual achievements. The Academie des Sciences in particular has a long list of prizes which are awarded from time to time to scientists who have solved specified problems or who have made advances along certain lines in Science. Living, the creative thinker is regarded as the glory of his country. When he departs this life his remains are buried in the Pantheon with funeral rites which vie with those accorded to a President of the Republic.

In the boy of promise, too, France sees the future man and treats him as a potential asset. He does not need to stop short in his education because his parents are poor. There are bourses awaiting him from the Commune, the Department, and the Government. Where his gifts justify it, he will be provided with the best education which the country can offer. In the advanced classes of certain of the Lycées as many as 75% of the pupils hold bourses. The Government maintains schools of university grade for genius. Entrance to these schools is by competitive examination and the number to be admitted each year is limited. Such schools are the École Normale Supérieure and the École Polytéchnique. In the École Normale literary and scientific studies are both provided for. On the literary side the number admitted annually is limited to 30, on the scientific side to 22. The number of

candidates for admission in science is normally about 150, all young men of exceptional ability. Of these then about 85% are rejected. It is to be noted also that of those accepted many will have made the attempt more than once. Conditions are pretty much the same in regard to the literary candidates. The students at the École Normale follow the lectures at the Sorbonne. They also have special courses of their own, which are sometimes supplementary to those of the Sorbonne. They live in residence, study under direction, have a library at their disposition and work in their own laboratories. After three years in residence, the students are again sifted by examination. The most gifted are directed toward the career of the university professoriate. The others supply a brilliant nucleus for the teaching staffs of the Lycées. Those students whose way has been paid by the Government are under obligation to take service with it for ten years and it in turn is under obligation to furnish them with employment. Half the students at the École Normale are under these conditions.

The number admitted annually to the École Polytéchnique is in the neighbourhood of 200. These would normally constitute about 20% of those who write on the examination for entrance. The course at this great engineering school lasts for two years, after which the student is sent on to the École des Mines, the École Centrale, the École d'Artillerie or some other school for a practical course. Of this school Joffre, Foch, Pétain, Nivelle, and others of the more notable French generals in the war just past are graduates. It was with a certain satisfaction that one learned that a Frenchman had been appointed General-in-Chief of the Allied Armies; for it was practically certain that he would be a graduate of the École Polytéchnique. This would be a sure guarantee of his intellectual calibre, for he would be select among the select. One could rest assured, too, that on top of his course at the École Polytéchnique he would have received an advanced technical training proportioned to his natural ability.

There is a strong mathematical trend to the training given in the École Polytéchnique and it is quite remarkable what a number of famous mathematicians have been turned out by this school. It is hardly necessary to add that graduates of the school whose way has been paid by the Government are under obligation to take service with the Government. The Government, too, finds good use for their services, not alone as officers but also im inportant civil capacities.

The candidate who fails to obtain entrance to the École Normale or the École Polytéchnique may have better success with the École des Mines or the École Centrale, schools also with limited admission. In any case there will be nothing to prevent him hearing lectures at the

Sorbonne, for attendance on the courses given there is not limited as at the other schools I have mentioned.

In England it will shortly be as in France that the boy of exceptional ability will be able to pursue his studies as far as he will however indigent the circumstances of his parents may be. At present there is nothing to prevent him completing his course in the secondary school, for plenty of scholarships to that end are offered by the county councils. There are also more than enough scholarships in classics for entrance to the universities. In science and moderns, however, such scholarships are lacking. The funds to redress the balance here have been promised, so I am told, and it will not be long until arrangements have been made which will provide for carrying the boy of outstanding ability right through the secondary school and the university, or higher technical institution of university grade, and training him for research if his tastes incline that way.

The experience of the Naval Dockyard Schools in England furnishes an interesting commentary on the amount of brain waste there must be in classes of the community where better educational opportunities are not available. The schools here referred to are conducted for the benefit of shipwright apprentices who work in the Dockyards. The apprentices who distinguish themselves in their studies are transferred to the Engineering College at Keyham for a year, and if their showing justifies it, they are then sent on to the Royal Naval College at Greenwich for the three years' course at that Institution.

The majority of the present Constructive Staff at the Admiralty Dockyards were formerly students at the Dockyard Schools. These same schools have furnished a succession of distinguished Directors of Naval Construction at the Admiralty. Among these one might mention Sir William White, the designer of the pre-dreadnoughts, and Sir Phillip Watts, designer of the first dreadnought; others are Sir E. Reed and Sir N. Barnaby. Sir J. Marshall, who started as an apprentice in a Dockyard School, became, later on, Director of the Dockyard. Sir J. Biles, Professor of Naval Architecture at Glasgow, had the same start and this was the case also with Mr. S. J. P. Thearle, formerly Chief Surveyor of Lloyds'. Others could be named who have occupied or who are at present occupying commanding positions with some of the largest private shipbuilding concerns in Great Britain.

What a pity it would have been had such precious material been lost to Great Britain. What a pity it is that so much material of like character has been lost and is being lost to Great Britain and the Empire. What a pity it is, too, that in Canada no adequate effort has been made to salvage equally good material.

The indications are that Great Britain will, in the near future, realize more largely on her latent intellectual resources than she has done in the past. To compete with Germany in technically trained men, however, she will have to increase the flow of students from the secondary schools to the universities and higher technical institutions by every means at her command. Mr. Fisher's education bill will help greatly to that end when it comes completely into force 7 years hence. Under its provisions a pupil who has reached 14 years of age will have the alternative of continuing his studies on full time for 2 years longer or of studying part time until he reaches 18. This will bring him to within sight of entrance to the university. The indications as to who should take a university course ought to stand out fairly definitely by this time and the scholarships referred to above will, no doubt, make their appeal to the ambitious student.

In a recent number of Nature,* Professor R. A. Gregory has given some figures with regard to the relative attendance at Universities in England, Scotland, Wales, Ireland, the United States and Germany, from which a little analysis will draw rather interesting conclusions. The number of university students per ten thousand population is approximately 14 in Germany, 10 in the United States, 5 in England, 17 in Scotland, 7 in Ireland, 6 in Wales. In giving the figure for the United States, Professor Gregory has based it on the 72 universities on the accepted list of the Carnegie Foundation. In Canada, as a whole, the figure would be about 15 and in Ontario it would bulk somewhere in the neighbourhood of 25. Here no account has been taken of the difference in standards for entrance to the universities in different countries or of the difference of age at which the student is prepared to enter. In Germany the average age at which the student leaves the gymnasium is between 20 and 21. In Great Britain the usual age of entrance to a university is between 17 and 18, except in the case of Oxford and Cambridge where it is between 19 and 20. With us the normal age of matriculation is 18 and it is about the same in the United States. Taking these facts into account it will be seen that most of that which passes as university work in Great Britain, Canada, and the United States would be of gymnasial standard in Germany. If we would compare the number of students in the several countries, on the basis of the university standard in Germany, we would probably not be doing injustice to any of the other countries concerned by giving for every 10,000 of population the figures 14 in Germany, 3 in the United States, 3 in England, 6 in Scotland, 3 in Ireland, 2 in Wales, 5 in Canada, 8 in Ontario.

*August 15, 1918.

While in Paris last summer, I found that the total attendance for the year 1913-14 at universities and other educational institutions of university grade in France was in the neighbourhood of 26,000. This is at the rate of a little more than 6 per 10,000 population. It would hardly be necessary to cut this figure down as much as we did with the corresponding figures for the other allied countries. In comparing the university status of France with that of Germany, too, it would only be fair to take account of the selective policy adopted by the former country with regard to the intellectually gifted.

One must not be too hasty in finding implications in the figures we have mentioned or in drawing conclusions from them. They do not imply that the intellectual status of Germany compared with that of England is as 14 to 3, nor do they give the relative positions of the two countries in regard to scientific achievement. The scientific status of a country is determined principally by the quality of the output of its foremost research workers. The status of England in science compared with that of Germany is in the aggregate, no doubt, higher than that given by the ratio 3 to 14. This would seem to indicate that among the scientists trained in England is to be found a larger proportion of high grade ones than is the case with those who are trained in Germany. This may or may not imply a smaller proportionate waste of scientific material among the men of highest intellectual capacity in England than among those who are of a somewhat lower grade. It might imply that the average intellectual level of the classes in England from which the ranks of science are recruited is higher than that of the classes in Germany from which science draws her recruits. My own impression is that the average Englishman has been endowed by nature with more intelligence than the average German. There can be no doubt that the amount of brain power which is undeveloped and which goes to waste in England is something enormous. The one thing that the figures just given do tell us is that in Germany there are more young men in proportion to population who prolong the period of their studies and receive an advanced training than there are in other countries. Of these young men science secures its full share. As a consequence a larger number of highly trained men are available for the purposes of science and industry in Germany than elsewhere. It would appear that men of such training have been spared by Germany during the war as they have not been spared by the Allies.

Two months ago, while in London, England, I had a conversation with Dr. E. C. Worden, chemical expert of the Bureau of Aircraft Production, Washington, D.C., who had been commissioned to report on the chemical factories in the occupied portion of Germany. He had

furnished detailed reports on 62 chemical factories. The largest of these was the factory of the Bayer Company, at Leverkusen, 12 miles from Cologne. At this factory over 3,000 tons of pharmaceuticals, dyestuffs, and other chemicals were awaiting export. The plant is equipped with 3,500 telephones. At the time of Dr. Worden's visit over 500 research chemists were at work, and to these several hundred more would be added as soon as the raw materials were available. According to Dr. Worden Germany kept her technical forces unimpaired by the war. She placed her technical men in positions where they did not run too much risk.

An economic blockade has been divested of some of its terrors for the Germans, for the Haber process has been so improved that they can obtain an ample supply of nitrates from the air. Their agricultural needs in this connection, Dr. Worden states, will be satisfied for all time. At the Badische Anilin und Soda Fabrik, located near Ludwigshafen, above Coblenz, on the Rhine, they are in a position to extract the nitrogen from 2½ cubic miles of air daily. This Company has a new research laboratory which, with its equipment, cost $750,000. In many cases where the Germans used a chemical plant for making explosives, they erected in the neighbourhood a substantial factory on a scale at least equal to that of the plant which was being utilized for war purposes and the factories so erected were all held in readiness to begin operations as soon as the war was over. The expectation was, of course, that these new plants would be paid for by the Allies and no expense therefore was spared in their preparation. It is hardly necessary then to remark that Germany, so far as the chemical industry is concerned, is in splendid condition to resume competition with the other nations of the world.

It evidently behooves the Allies to increase not only their university attendance but more particularly also their output of research workers. This would be advisable under any circumstances. It becomes doubly urgent in the face of a German competition backed by an ample supply of scientifically trained workers. Nowhere is it more necessary to take stock of one's scientific position than it is in Canada.

The figures already given for university attendance do not appear to place Canada in an unfavourable light as compared with countries other than Germany. Gauged by the second set of figures, however, Canada, as a whole, and even Ontario, shows to disadvantage in comparison with Germany. The actual disadvantage, too, is greater than that implied in the ratio of 8 to 14. For the 8 Ontario students would, on the average, be less mature than the 14 German students and would include among them a smaller proportion who are engaged on more

advanced work and preparing to do research. If we limit ourselves to the upper ranges of University work, that is to say to the preparation of research workers, Canada hardly compares with the United States and Ontario itself is quite outclassed by certain States of the Union. It may be remarked, however, that we in Ontario are getting under way.

I have referred to the assistance in the form of scholarships and bourses extended to the poor boys in England and France. We have nothing that corresponds to this in America. Our idea of a scholarship is a comparatively small prize not at all proportionate to the keep of a boy for a year, let alone several years in succession. Our nearest approach to the English conception of a scholarship is what we call a fellowship. This, however, is only available to a graduate student. The attached stipend is usually a meagre one and the fellowship may or may not be renewable for a second or third year. It is often utilized, too, as a pretext for securing a certain amount of cheap teaching.

The fundamental defect in the educational systems on the American continent is the failure to make adequate provision for the training of the exceptionally gifted. It is quite evident that funds must be provided for the care of the mentally defective. A proposition to help those who are backward in their studies will receive a sympathetic hearing. If, however, it were proposed that the State should spend money in establishing a school for genius after the model of one or other of those which are supported by the State in France, the cry of class privilege would be raised. If there were question of extending financial aid in their studies to one or other of two boys, the first of whom was exceptionally gifted, the second of mediocre capacity, and if the man on the street were consulted in the matter, he would more likely than not advise that the money be given to the second boy on the ground that he was already handicapped in competition with the first boy.

With France we should learn to realize that the exceptionally gifted individual is there for the good of the community. All the ameliorations which we enjoy we owe in the last resort to such individuals. The State, then, may well defray the cost of their training for it will ultimately profit more from the expenditure than those on whom the money is expended. One creative worker who adds an increment to the heritage handed down from generation to generation ultimately means more to the nation and the race than a hundred mediocrities trained to their capacity. No number of trained mediocrities could compensate for the loss of a Newton.

Whether America has lost one or more Newtons no one can say for certain. But that many, very many, who should have done creative

work of a very high order have, because of defective educational facilities, failed to achieve their destiny, there can be no doubt. Because of this America in particular and the world in general are so much the poorer.

A generation ago American university conditions were something appalling. In my own department students were everywhere misled. The only way in which one could get an adequate grounding in the calculus was by going to Europe. This subject, which we have already referred to as the basis for most of the higher mathematical analysis, was practically everywhere mistaught. The result was that the potential mathematicians in America were sterilized. One of them, who after his American training had the corrective of a European experience and who now holds an honourable place among American mathematicians, told me ruefully that he would never recover from his early training. I have in mind another and younger man from whom his friends and teachers expected great things. His undergraduate training was of the kind referred to above. On top of it he completed a course in one of the best graduate schools on the continent. He has failed to make good, however. His graduate teachers attribute his failure to the false start given by his undergraduate training. I am inclined to accept this explanation for I know the man and I am convinced that he had the material in him to make a research worker. I have had my own experience in this connection. Fifteen years after I had received my grounding in the calculus I discovered, I am ashamed to say, in a German University, the University of Berlin, that it had been taught to me falsely, irremediably, and fundamentally falsely. A dislocation of fifteen years in one's scientific life can hardly fail to leave its impress.

There are other subjects, I am informed, in which instruction in American universities was almost as bad as that in mathematics a generation ago. Conditions, however, have greatly improved in the interval. A student would be tolerably safe now in accepting the guidance in mathematics offered in any of the larger universities. The like will, no doubt, be true of other subjects also. There is no longer the same urgency as formerly for a student to go abroad. Too much inbreeding, however, is not to be encouraged. A certain amount of circulation is healthful. A university, too, should avoid isolation. It should be in touch with other universities at home and abroad and ought to be familiar with what is going on in the outside world.

The change in conditions in American universities, the improvement in instruction which has taken place during the last twenty-five to thirty years, is due primarily to the initiative and self-sacrifice of hundreds of young men who, from time to time, crossed the Atlantic in pursuit of

knowledge. After years of study abroad these men returned to America with a new outlook and new ideas. They were imbued with the spirit of research and brought it with them into the universities where they received appointments. In the larger institutions there were developments along graduate and research lines. In universities both large and small, the research spirit reacted on the undergraduate work and vitalized it. Bringing a sleepy old text-book routine institution into touch with research has all the effect of connecting a stagnant pool with running water. There are still some pools that would be the better for a little more flow.

The research workers just referred to organized scientific societies. At the meetings of these societies, papers, containing the results of their researches, were read and discussed. Journals were founded for the publication of these papers. The scientific status of the United States and the universities within its borders rose in the eyes of Europe.

The American universities a generation ago were practically all high schools with the exception of the Johns Hopkins University. They are now a combination of university and high school, and in certain of them the research side has been considerably emphasised. The Johns Hopkins was a pioneer in research. It was founded primarily as a research institution. An important feature in its policy was the appointment of big men to its professorships. Big men, however, were not always available. Furthermore it was straitened financially. It did its best under the circumstances and that meant much. Brick and mortar held a small place in its programme and its buildings were less pretentious than those of the larger American universities in general. It established scientific journals and within a few years of its foundation, its prestige in Europe eclipsed that of all other universities on this side of the Atlantic. Other universities supplied with more ample funds have followed the example of the Johns Hopkins and have made research a conspicuous feature of their work. Most universities on this continent might take a lesson from the Johns Hopkins University in regard to the relative emphasis to be laid on men and buildings.

The improvement in the scientific and academic status of American universities during recent years I have attributed primarily to a number of individuals who studied in Europe and brought back with them to America the inspiration of research. To these are to be added scientific graduates of the Johns Hopkins University distributed among the educational institutions of the continent who had their share in leavening the academic sentiment and spreading the research idea. Those who now have charge of research work in American universities and those who are engaged in industrial research on this side of the Atlantic are,

for the most part, pupils of the pioneers in research of whom we have just been speaking.

The research men on the staffs of American universities have done all that is humanly possible for them to do to give efficient instruction in science and to improve research conditions in their institutions. It is up to the university administrators to do their share. Salaries must be increased especially in the junior grades and research men must not be overloaded with teaching. I could mention one of the largest universities on the continent whose policy it has been to pay its professors the minimum for which it could get them. A few years ago the head of a department in this university told me that the professors' salaries there ranged from $2,000 to $5,000 a year. The President was housed palatially. I could point you to another famous institution, known by name to every one in this audience, which has on its list professors who are in receipt of a yearly salary of $2,500 or $3,000. Before the war this institution paid its instructors the princely sum of $900 a year. A few weeks ago I learned that it was now anxious to pay $1,800 for a newly fledged B.A. as instructor in mathematics where it formerly expected to secure a man of Ph.D. grade for half that sum. This is one of the effects of the war. I could name a well-known university where they paid instructors $1,000 a year before the war. Promotion is none too rapid at this institution. Some years ago, so I was told, the head of one of the departments requested the President to increase the salary of one of his instructors to $1,500. The instructor in question was the strongest research man in his department. The President refused the request on the ground that he was not impressive looking. Fortunately, the man in question did not have to wait long for a call elsewhere. He is now professor in another university, where he receives a salary better proportioned to his attainments. An eminent scientist, who was formerly head of a department in an important state university, told me that his two assistant professors, who happened to be married men, were so poorly paid that they had themselves to do their family washing.

That the university administration in America does not always appreciate the efforts of the research man is illustrated in the case of a certain state university which had several men on its staff who were interested in research. These men had published a number of papers in foreign scientific journals. This came to the ears of the Board of Regents. As it happened the Governor of the State was a member of the Board and he lost no time in communicating with the offending professors and informing them that they were hired to teach and not to write. This story I have from a former professor of the university in question.

The administration of a university may not usually express itself in the same way as the State Governor just referred to, but its policy is frequently just as effective in discouraging research. The business administration of an American university when it comes to engaging instructors is apt to apply the law of supply and demand ruthlessly. It takes no account of the motives or ideals of those who are seeking positions on the teaching staff. Among the candidates may be one whose dearest desire in life is to find the opportunity to do research. This privilege he would not forego for anything which fortune or favour could offer him. He has already made his first contributions to knowledge and there is every reason to believe that nature has endowed him with gifts of the highest order. The findings of research appear to him to be the most permanent contribution to our civilization. The great pathfinders in science he regards as the highest product of the race. By identifying himself with science through research it seems to him that he associates himself more closely with the eternal than he can do in any other way. The only opportunity to do research would appear to lie in a university career. The administration offers him a beggarly pittance barely sufficient to hold soul and body together. This he accepts in the expectation that he will find the time for research. Vain delusion! He is loaded down with lectures and tutorial work on the general business principle that the more hours his employers squeeze out of him, the more they are getting for their money. This is the kind of policy which kills the goose that lays the golden egg. The years pass. Possibly our research man gets married. He has no margin to come and go on. Promotion comes slowly. Financial worries multiply. He finds himself at last compelled to abandon his long cherished plans for research. He broods over the futility of his sacrifices and eats his very heart out.

Some there are who are more fortunate, who find it possible to reserve a little time for research and who manage to produce, though under handicap. A few, too, there are who, after years of struggle, arrive in a position where they are masters of the major part of their time and can devote themselves to research, if in the intervening years their productive ardor has not abated.

If then scientific productivity in the American universities to-day is greater than it was a quarter of a century ago the credit therefore is due not to the university administrations, but, as we have already stated, to members of the academic staffs, which members are also responsible for the increased efficiency of scientific instruction in the universities. For the more advanced instruction these men often receive no remuneration. They are permitted as a privilege to under-

take this work in addition to their regular work. There is no eight-hour day for the research worker. For overtime he does not receive time and a half pay. He gives the extra time gratis. The layman may think that the scientist is paid for the articles he publishes in the technical journals. This, however, is not the case. He does this work gratis also. The editorial work on the scientific journals is, in general, done without remuneration. I may add furthermore that there is no money in the publication of a scientific treatise or a more advanced text-book.

The man on the street will say any one who does so much work gratis is not practical. There is this side of it, however, that when a man has toiled a lifetime to make a fortune, the very best that he can do with it is to endow research. His benefaction to the race is then of the same effect as that of the research worker. The man of wealth contributes indirectly to the welfare of mankind. He first acquires his wealth and then uses it to subsidize the research worker. The latter makes his contribution directly. Why should we say that he is less practical than the business man who has accumulated wealth? It may be that, under stress of circumstances, he consents to accept less than a decent living salary. The business administration of the university which is willing to take advantage of his position, however, can hardly be called practical for its policy is, in the long run, detrimental to the university, to science and to the best interests of the nation.

In European universities the position of research is less incidental than in the general run of American universities. In Germany the university is essentially a research institution and every member of the teaching staff, as we have already indicated, is appointed on a basis of research qualifications. Practically the same result is secured in France in another way. The professoriate there is recruited from the most select of the select material which is admitted to the schools for genius to which I have already made reference. In certain of the English universities the professorial standard is safeguarded by a system of so-called electors. For those who are not familiar with the system I may say that when a chair becomes vacant a number of men are named whose duty it is to select a man to fill the place. These are known as electors. They are usually men of technical knowledge. Certain of them are from the institution concerned. The others are outsiders. The principal evil the system is intended to guard against is appointment by local pull. The voice of the outsiders, I am told, is usually the determining factor in making the selection. I have in mind a case where there were five electors of whom three were from outside the institution. The two local electors felt under obligation to support a colleague who

was a candidate for the position. The outside electors, however, said that they must have a stronger research man and it was decided in this sense.

In America there are no recognized safeguards for the professoriate such as exist on the other side of the Atlantic. There are no traditional standards by which the candidate for a professor's chair must qualify. It is not always a question of scientific achievement. Local pull is frequently in evidence. Executive and committee work within the university and outside activities with an advertising value often receive their reward. Where, too, it is the intention of the appointing power to make the scientific status of a candidate the determining factor the scientific advice invoked is often far from competent. Some years ago the American Mathematical Society, recognizing the existing state of affairs, named a committee to consider whether it might not be possible to bring the knowledge and experience of the society to bear in the making of mathematical appointments in universities and colleges. The committee, however, reported that they were unable to devise any means for attaining the desired end.

The material which goes to make up the teaching staff of an American university is most heterogeneous. Not all the young men who enter the academic profession are of the idealistic type to which I have referred a little earlier. Their average, however, would compare favourably, I think, with the average in any other walk of life. They all look forward to professorships of course, and one or all may ultimately arrive. Promotion in an American university is slow. The gradations leading up to a professorship are more numerous on this side of the Atlantic than in Europe. Though the scientific qualifications in America are on the whole less exacting than in Europe, advancement, for the man of ability at least, is not as rapid. The man of high attainments will find himself a professor at an earlier age in Europe than in America. However it may be in other departments of human activity America is not the land of the young man in the field of academic work.

I have taken occasion to speak of the overloading of members of the American universities' staffs with teaching. This had reference to the professors in general as well as to the junior members of the staffs. The number of lectures which a professor in an American university is called on to give is much in excess of that demanded of his European compeer. In response to a question of mine as to the number of lectures which he was expected to give in the course of a year, a professor on the staff of Oxford told me that his position required him to lecture 28 hours in the course of the year. As a matter of fact, however, he lectured 56 hours. In France a professor is expected to lecture 3 hours a week. This is

usually for the academic year of 30 weeks though some of the professors in Paris are only required to lecture 15 weeks. In Germany it is stipulated that the professor lecture at least 2 hours a week throughout the academic year. He, usually of his own volition, gives more than the stipulated number of hours. He is not troubled by the limitations of a fixed curriculum, it may be noted. He lectures on subjects of his own choosing and rarely on more than two at a time.

In America it is nothing out of the ordinary for a professor to give from 300 to 500 lectures in the course of a year. The layman may fancy that this is not too much and he is likely enough to jump to the conclusion that the European professor has a very easy time of it. Let us see, however, how it works out. The European professor is in a position to concentrate on one subject at a time. It may be that the literature on the subject is not organized up to date. For the purpose of his course of lectures it will be necessary to organize it. To digest and collate the scattered material is likely enough to be a task of some magnitude. It will probably be as much as he can handle. It may be that it will take him several years to do the work. Here and there, by the way, he may delay over a point which needs to be cleared up or a problem whose solution would be useful. However that may be one result of his labours will, as likely as not, be a treatise which will be of service to many more individuals than he could reach by word of mouth in the class room. These individuals would be located in different countries and distributed over the surface of the civilized earth, including among them seasoned research workers as well as immature students. Occasionally, too, the lectures of a creative thinker will consist largely in the exposition of successive discoveries which he is making in the course of the development of a subject.

The lectures of an American university professor will rarely be of the character of the lectures to which we have just referred. They cannot have such character if they are to run into the hundreds annually. As a matter of fact many of the so-called lectures in universities on this continent consist entirely of text-book work and are purely tutorial in their character. This is necessarily the case in institutions which are half high school and half university.

The typical American professor who lectures on a multiplicity of subjects simultaneously can hardly concentrate on any one of them. He certainly cannot concentrate on all. He has to be perpetually changing interest as he jumps from one subject to another. He has to be content with placing himself in position from day to day with regard to the successive parts of the several subjects, and the position in which he places himself is pretty much the same from one year to another so

that the same lectures are repeated from year to year and finally become a matter of routine.

The lecturer who concentrates on one subject at a time, and changes that subject from year to year or at longer intervals, covers a much larger territory in the end than the man who drives the same half dozen subjects abreast year after year. Besides this he has a much better command over his material. The conditions best adapted to the needs of a scientist, the conditions under which he will attain his maximum as a research worker and prove himself most efficient as a teacher, are not always clearly apprehended by American university administrations.

The American university is administered by a Board of Regents composed wholly or almost wholly of business men. There is a President appointed by the Board and appointments to the teaching staff are made by the Board on the recommendation of the President. In general the Faculty has no representation on the Board and its sole connection with the Board is through the President. There is a good deal of dissatisfaction with this arrangement, I was told while on a visit to the United States last summer. A prominent member of the academic staff of one of the principal American universities gave expression to this feeling by stating that the teaching staff was slave to the administration. There have been some experiments in the way of modifying the organization. Representation of the Faculty on the Board of Regents has been tried. There have also been committees of the Faculty having access to the Board and committees composed of members of the Board and members of the Faculty. With what success these tentatives have met I do not know. There does not seem to be complete unanimity with regard to the remedy which is needed for the existing state of affairs. I may say that in European universities there is no administrative body of the nature of the Board of Regents of an American university and there is no office which corresponds to that of the American university President. The Principal of a British college or university has nothing like the powers of the university President. The Faculty has far more influence in the conduct of affairs than is the case in America. This is in evidence in the making of appointments. For example, where the system of electors is in operation the Faculty has a voice in choosing the electors. It also has its say in the case of universities where the system of electors has not been adopted.

In our Canadian universities we have the American form of administration. Our curriculum and academic standard, however, have been imported from Great Britain. We have adopted the idea of the honours courses, and these courses at the University of Toronto are probably

the heaviest undergraduate courses on the continent. With this foundation one would have said that we should have developed along graduate lines more rapidly than has been the case. Some of the American universities, however, have greatly outdistanced us in the development of graduate and research work. Let us hope that we shall overtake them. Our students who have received their bachelor's degree in one of the honours courses compare more than favourably as a rule with those who have completed an undergraduate course in the corresponding department of an American university. The result of a comparison with the best product of the universities on the other side of the Atlantic is, however, not so favourable. The conception of a university at its best is on a somewhat higher plane in Europe than in America. The same is true also of the secondary school. A young man of exceptional ability being trained in Europe is likely to be somewhat in advance of where he would find himself at the same age if he were being trained in America. On entering Oxford or Cambridge a student specializing in mathematics is about two years ahead of a student entering the University of Toronto in the same department, while he is just one year older. The discrepancy in classics is quite as great. This does not hold in the case of the natural sciences which receive less attention than mathematics and classics in the Public Schools of England. From what we have just said, however, it would appear that it should be possible to so modify the methods of instruction in our Canadian secondary schools as to save a year to our brighter boys by the time they are ready to matriculate. A comparison with results obtained on the continent would lead to the same conclusion.

The university attendance in the Province of Ontario in proportion to population compares favourably with that of any other country except Germany, after all due allowance has been made for inequality of university standards in different countries. Nevertheless 6 out of 7 pupils who pass the High School entrance examination never matriculate. About 7 out of 9 do not attempt the matriculation examination.* Among these boys and girls there are sure to be many who would profit by a university course. Much good material must here go to waste. Why should we not have in Ontario, or better still throughout Canada, a system of scholarships which would provide the highest possible education for the exceptionally gifted? Australia makes such provision for her gifted boys and girls. Why should we do less for ours?

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*The figures here given are based on the results for the matriculation examinations during the five years 1910-14, and on the results for the High School entrance examinations during the five years 1906-1910.

The waste of brain in this world is a tragedy of the first order. There is none greater. This was brought home to us with peculiar emphasis during the war. When Moseley was killed at Gallipoli scientists everywhere felt a sharp pang. Here was a young man who had crossed the threshold. He had just had time to prove his genius. Almost at his first attempt he left his imprint on the science of physics and great things were expected of him. His sudden cutting off did a great violence to the sense of the fitness of things in the minds of those who knew what a loss it meant to science. The toll of Trinity College, Cambridge, in the war was in the neighbourhood of 2,000. Of these some had already been productive and others gave great promise. The most gifted of our young men went overseas and many of them will never return. Among the latter were two of gold medallist standing in my own Department. The sacrifice of a young man of exceptional ability seems to accentuate the unreason and injustice of warfare. Why should he not have been permitted to fulfil his natural destiny, to lead an intellectually productive life and perhaps add a permanent increment to the heritage of the race? Yet the same sacrifice of exceptional gifts, the same waste of brain power, is going on regularly in our midst in peace times and we pay no attention to it. What is possible in this regard I have illustrated by the history of mathematics in America. Successive generations of potential mathematicians were wiped out. They never knew what struck them. Their contemporaries never knew that nature intended them to be mathematicians. The story of the Dockyard Schools is full of suggestion as to the waste that must be going on. We pause to think when we hear of a man like George Green, who was discovered at 40, graduated at Cambridge at 44, and died at 48, after leaving his permanent mark on the history of mathematics and physics. It is said that his later years were saddened by the realization of the fact that the greater part of his life had been wasted. How many George Greens are there who die before 40? How many who are not discovered before 48?

There is no general formula which will enable us to avoid all waste of brain but we should endeavour in every possible way to salvage all we can. It would, no doubt, be helpful to have the advantages of a university or higher technical education presented from different viewpoints to the pupils in the secondary schools, preferably by visiting lecturers. Their studies, too, should include something of a biographical or narrative character touching on the lives and work of the great scientists. This might even with advantage be introduced into the elementary schools. Matter could readily be selected which would not be lacking in romance.

Some adequate reference it seems to me should be made to science in the teaching of history in the schools. Modern history, as I understand it, is an account of how a people, starting out under certain conditions at a given time in the past, have arrived at where they now find themselves. The most important agent involved in the transition, the largest factor by far concerned in modifying the conditions of living during the past two centuries, has been science. Is it not of the first importance that every boy and girl should be made aware of this fact?

By stimulating the interest of the pupils of the preparatory schools in science, by visualizing university opportunities and by establishing a system of scholarships such as we have already referred to, we could doubtless increase considerably the number of students of ability in our universities. Those who do not go to the university, but leave the elementary or secondary school to earn their living, would at least carry away with them a certain respect for science and a recognition of the fact that the university has a useful function to perform in the life of the community. This would later on have its effect in helping to create a public opinion which would react more favourably to proposals for financial aid to universities and science.

A university should be sufficiently staffed to care for the needs of its students. Our own University is undermanned. The tutorial classes should be smaller. This is no good reason, however, why the members of the staff should be overworked. Junior instructors, who have research inclinations, should be given a chance to show the mettle that is in them. The more mature men, who have already proved themselves, should be given time for research. Only yesterday I was talking to a member of the staff who told me that for three weeks past he had been working till three in the morning and that for seven days in the week. The man in question is a research worker, but the work referred to had nothing to do with research. This is, of course, exceptional and it will not ordinarily be necessary for my colleague to work so strenuously. Even so it is a little inconvenient. The same man, too worked till midnight daily during the last month of the vacation getting the materials required in his laboratory in readiness for the opening of the term. I asked him whether he received any pay for work overtime. His reply was an incredulous smile which, interpreted, meant how could any member of a university staff be so ingenuous as to ask such a question.

The case I have cited is an extreme one to be sure. There are plenty of members of the university staff, however, who have more than enough to do and there is none who has not enough to keep him busy. Of this the layman can rest assured. Further staff, of course,

would mean more expense, but the Province would be well paid for its extra outlay.

There should be a larger number of places for research men in Canada. There should be more positions for them in the universities and more in the industries outside. The University of Toronto has begun to develop along research lines and in the course of time, no doubt, much good Canadian brain power will be salvaged which would otherwise go to waste. The projected Institute for Research at Ottawa will absorb some of the men trained by the University for research. It is to be hoped that the demand from the industries will grow. It might be well also to base such men in charge of the science departments in the high schools and to encourage their research inclinations by furnishing them with adequate laboratory equipment. Something of this sort, I understand, it is proposed to do in England.* This would all tend to conserve Canadian brain for Canada and would check the leakage to the United States and other countries. Of the 15,000 living graduates of the University of Toronto, 1,700 are located in the Republic to the South of us. Between 400 and 500 others are domiciled abroad. McGill's loss to the United States is 1,500 out of 6,700 graduates.

It has been suggested that research professors and research associate professors be appointed in the departments of natural science of the University of Toronto, their duties to consist primarily in the prosecution of research on their own account and in the training of young men of selected ability for research. The aggregate of these research men would be known as the research staff in natural science of the University of Toronto.

To me it appears that the organization of such a group would, in addition to creating greater effectiveness within the university, have a two-fold benefit without. On the one hand it would remind the laymen that there exists a body of men in the world whose business it is to advance knowledge and on the other hand it would impress on them the fact that the University is not an institution whose sole function is to purvey knowledge, but that it has also another and quite as important function, namely to add to knowledge and to train young men in order that they may add to knowledge in their turn.

The war has been wasteful of brain power. It has, however, taught us its value. In the work of reconstruction nothing can be of more importance than conserving and realizing on the brain power of the nation. In this work the universities must play the leading role. If

*A provision in the Education Act enables local authorities to meet the cost of research work of educational value conducted by teachers in the schools.

in our reconstructed country we shall have reduced brain waste to a minimum and increased brain output to a maximum, we shall have raised the greatest of all memorials to our boys who sacrificed themselves in France and Flanders in order that Canada should be saved from determination by Germany. It is for the Canada whose destinies will be determined by Canadians that they fought and died and the Canada that is to be will be their monument. Let us make the monument a great and noble one. May it be worthy of those whom it commemorates.

AGE-DETERMINATION, GROWTH AND SYMMETRY IN THE TEST OF THE ASCIDIAN, CHELYOSOMA.

By A. G. Huntsman, B.A., F.R.S.C.

Comparatively little is known concerning the growth of Ascidians, except during early life. Their embryonic and larval development has been studied repeatedly, as well as the growth of the young individuals during a single season or a year, but so far as we are aware, no attempt has ever been made to determine their length of life or to compare the amount of growth in successive years. Methods have been developed in recent years for determining the age and for studying the growth in the group of the fishes, use being made of the zones or lines of growth that are to be seen in bones, otoliths or scales. The genus *Chelyosoma* is peculiar among Ascidians in having the test in the neighbourhood of the apertures modified to form definite plates. The latter are outlined by grooves in the outer surface of the test, at the bottom of which the test is quite thin and flexible. Special muscular bands passing from plate to plate are attached to processes of the inner surfaces of the plates, and move them upon each other. These plates show lines of growth which, if our interpretation be correct, make it possible to determine the age and study the growth of an individual.

We have extended this investigation to show the order and symmetry that obtain in the arrangement and in the mode of formation of these plates in the three species of *Chelyosoma* that we have studied.

Chelyosoma macleayanum, Broderip and Sowerby.

Our material consists of a number of specimens from the Alaskan coast near Point Lay and Icy Cape collected by Mr. F. Johansen of the Canadian Arctic Expedition in August, 1913. In the two smallest specimens, which are quite clear or whitish and 3 and 6.5 mm. in length, the plates are plain and without any indication of interrupted growth in the form of lines. All the larger individuals are yellowish or horncoloured, which colour is in the test. In these each plate shows more or less clearly a series of lines running parallel to the edge of the plate. (Pl. 1, fig. 1).

Broderip and Sowerby, who gave the first account of the genus and of this species, (1) noticed three or four of these lines in each plate in a specimen from the Arctic regions. In the siphonal plates these lines are parallel to the base or hinge margin and cross each plate from side to side. In the remaining plates each line is endless and encloses an

(1) Zoolog. Journ., Vol. 5, p. 46, 1829.

area which is a miniature of the entire plate. It is quite evident that these are lines of growth, which represent the margin of the plate at successive stages in its growth. We interpret these lines as "checks' in the growth of the test, that is that growth is periodic and that its renewal after a period of quiescence produces a definite line. The principal periodicity in conditions is that of the seasons, winter alternating with summer. In boreal or arctic regions the high temperature of summer is more favourable for activity, reproduction and growth in the majority of animals than is the low temperature of winter. It has been observed that Ascidians reproduce and grow during the summer and that during the winter season some species are in a reduced or quiescent state, with more or less of the body sloughed away to be regenerated in the spring. We are, therefore, justified in assuming that the lines of growth in the plates of *Chelyosoma* represent winter periods with a lessening or a stoppage of growth, and all the available facts support this assumption. The retention of the winter border of the plate as a line is perhaps to be explained as the result of the hardening of the outer part of the test, which would mean that, when growth is interrupted for a time long enough to permit of the test at the edge of the plate hardening, the new growth is unable to lift up the turned-in edge of the plate and a groove remains between the old test and the new. The hardening of the test is due in part at least to the formation of a special outer layer, the yellow layer as it is called by Bancroft (1898, p. 317), (2) who has described it for *C. productum*. It is comparatively thin and "is slightly harder, stiffer, and more brittle than the tunicin layer". Bancroft describes its origin as a secretion from mesodermal bladder cells, which move to the surface of the test and finally degenerate. In this species these cells are quite regularly arranged at the surface and each is surrounded by a more or less definite zone, which is apparently the product of its activity. Bancroft has described the formation of a deposit of the yellow substance just inside and just outside the cell membrane of the bladder cell and states that "of those nearest the surface nothing can be seen but a small vesicle containing some refractile material in which usually not even the remains of a nucleus can be made out". In the newer portions of the yellow layer, these cells are larger, and the zone of yellow substance surrounding each one is more distinct than is the case in the older portions. If the lines of growth are to be used in calculating the growth of the plate or of the individual in successive years, it is necessary that there be no interstitial growth in the old portion of plate.

(2) The Anatomy of Chelyosoma productum Stimpson. Proc. Calif. Acad. Sc., Ser. 3, Zool. Vol. 1, pp. 309-332.

That the yellow layer increases only by additions at the margin of each plate is indicated by the following facts. The cells are arranged in a fairly regular manner. They are as numerous in the newer portions of the plate as in the older. When a zone, presumably annual, of a plate has been completed, the yellow layer ceases to increase appreciably in thickness. The older portions of the yellow layer show no intercalations of incompletely degenerated cells with distinct zone of newly formed yellow substance, although such cells occasionally appear on the inner side of the yellow layer. The zone of the plate in process of formation, that is the one next the margin, is not so yellowish in colour as the older zones. In section the yellow layer in this zone is thinner toward the turned-in margin of the plate, and is absent from the bottom of the groove separating this plate from the neighbouring one, although, as is apparent in a surface view, the cells are not less numerous toward this margin. It would appear that at the growing margin certain cells reach the surface and begin the production of the yellow substance, which production is completed by the cells before a new season of growth has begun. When the available space has been occupied by cells, no others can reach the surface and further production of yellow substance is prevented. The production of yellow substance by the marginal cells apparently does not cease when the margin fails to extend, so that the full thickness of the yellow layer is attained at the margin before the growth of another season begins, and thus the turned-in condition of the margin at the winter stage becomes set.

By means of the lines of growth we have calculated the ages of the Alaskan specimens and we give them herewith, the numbers in each case including the uncompleted year.

Year	1st	3rd	4th	5th
Length of disk in mm.	6.5	16	19	20
	3	19	20	45
			22	33
			24	
			33	
			37	
Average length	5	18	26	26

There is considerable variation in size among those of the same age.

In those over one year in age we have calculated the sizes of the various winter periods in their history in the following manner. Several plates were selected in which the lines were particularly distinct. The

length of a certain diameter in each plate for each winter period as shown by the lines was then measured and the percentage that its length at each winter period was of the present length was calculated. The average value of the percentage for each winter period for the various plates was taken and from this the length of the individual at each winter period was obtained by calculation. We cannot claim any great accuracy for this method, but it is sufficiently accurate for our purpose.

Length in mm.	1st Winter	2nd Winter	3rd Winter	4th Winter
16	5.8	10.4		
19	7.3	13.9		
19	5.1	9.1	15.9	
20	5	9.6	14.3	
22	6.3	10.6	15.5	
33	7.9	17.3	28.8	
37	8.2	15.5	27.7	
25	8.6	14.1	19.8	23.8
33	9.1	17.9	25	30.4
Average	7	13.1	21	27.1

The character of the growth shown by these individuals varies greatly. The annual increments in length may decrease steadily with age, may decrease and then increase, may at first decrease, then increase and finally decrease, or may at first increase and then decrease. On the whole this species for this region shows a growth sustained with little diminution for more than four years.

Certain aspects of the growth are of considerable interest. The superficial division of the disk into plates is seemingly a necessity arising from the continuity and rigidity of the yellow layer. If the latter were formed over the entire surface, increase in size would be impossible without rupturing it and it might be doubted whether in view of the presence of extensive cavaties in the animal connected with the exterior the pressure due to growth could ever rupture the layer. The presence of definite lines along which there is no deposition of yellow material and on either side of which growth can take place, permits of the test enlarging with the growth of the animal. These lines are made very definite by the action of muscles. A characteristic feature of the life of an Ascidian is its expansion, which is a preliminary to the commencement of feeding by means of the water-current, and its contraction when disturbed. These movements are effected through circular and longitudinal muscle

fibres in the body-wall. In *Chelyosoma* the rigidity of the yellow outer layer of the test tends to prevent such general movement, great flexibility being present only along the lines where the yellow layer is lacking. It is natural, therefore, to have the muscles more or less restricted in extent, and passing on the whole from plate to plate perpendicularly to the margins. Expansion and contraction can take place only between the plates, the disk as a whole being very convex in the expanded condition and flat in the contracted. In contraction the plates are separated by deep, narrow grooves. The attached part of the test has no yellow layer deposited on its surface, and its enlargement presents no difficulty. The mode of enlargement of the remaining part of the test, namely that between the disk and the attached surface, is similar to that of the disk. This part shows a variable network of lines, but no definite grooves like those between the plates of the disk, owing to the absence of intrinsic muscles connecting the areas. Along these lines the yellow layer is absent, and enlargement, therefore, is possible. Near the disk these lines form irregular plates, which are indistinctly in series with those of the disk. As the grooves separating these plates are very superficial, the formation of lines of growth would be unlikely to occur, and in fact none were found.

The formation of the plates is based upon the apertures. As is so frequently the case in related genera of Ascidians, the apertures of *Chelyosoma* are surrounded each by six lobes of the test and are borne at the extremity of more or less distinct siphons. It is natural, therefore, for the yellow layer around each orifice to be divided into six plates corresponding to the lobes and extending to the base of the siphon. The number of plates around each orifice is not absolutely constant, Bancroft having observed both five and seven plates around the atrial orifice in *C. productum*. In *C. macleayanum* we have failed to observe any variation from the typical number. Beyond the siphonal field there is a single series of plates for each aperture, which we may call the extrasiphonal, those for the two apertures fusing together more or less perfectly into one series, the margin of which is the edge of the disk, elliptical in outline with the aperture forming the foci. In the present species this series shows five plates for the oral and four for the atrial aperture, one plate (the central) being common to the two apertures (See Pl. I, fig. 2). The number and arrangement of the plates in this series are more variable than with those of the siphonal series. Bancroft has divided them into *central* (between the siphons), and *peripheral* (next the margin of the disk). The latter are divided into *lateral* (touching the central plate) and *anterior* and *posterior* (touching only the siphonal plates). We have observed an additional lateral plate on one or both sides, and only one

anterior plate in place of the usual number (two). That the division of the disk into certain definite plates is a very fundamental feature in the structure of these animals is shown by the constancy in the relation of the muscles to the grooves separating the plates. Each groove has usually along its entire length a series of short muscular bands, which connect the adjacent plates and hold them together in the contracted condition of the animal.

It is surprising that there should be a lack of correspondence between the siphonal and the extrasiphonal plates both in number and in arrangement. In spite of this a certain order is apparent. The four extrasiphonal plates are symmetrically arranged, there being an anterior, a posterior, a right and a left. The condition of the lobation of the apertures in certain other Ascidians indicates a primitive division of the apertural margin into anterior and posterior halves. Each half may be subdivided into right and left halves. Such a method of division of the apertural margin characterizes the families, *Botryllidae*, *Styelidae*, and *Tethyidae* (*Cynthiidae*).

In the atrial extrasiphonal region of *Chelyosoma macleayanum* (See Pl. I, fig. 1) there can be no doubt that the grooves are diagonal and that two of the plates are median in position, in this way being the reverse of the condition in the *Stylelidae*, etc. The oral extrasiphonal plates are the same, except that the anterior plate has been divided into two, although occasionally undivided, giving a median groove. The atrial siphonal plates are six in number and are referable to those in the extrasiphonal region by considering that anterior and posterior plates have been subdivided, the lateral one remaining undivided. The homologies of the oral siphonal plates are not so apparent. There is considerable variation in the position of the plates with reference to a median line passing through the two apertures but usually such a line nearly bisects an anterior and a posterior plate, which should be considered as median in position. Such a condition may be derived from the simple one of the atrial extrasiphonal series, by a division of each lateral plate into two. This would mean that both apertures are primarily four-lobed, the lobes being separated by diagonal clefts, and that the six-lobed condition is attained at the oral aperture by a division of the lateral lobes, and at the atrial by a division of the median. The plates, therefore, are related to the apertures and may be considered as formed by a series of divisions, the first two being diagonal, and the later ones median and transverse (See text fig. 1).

While the siphonal areas are quite definitely circular, the disk departs considerably in shape from an ellipse, being broader behind than in front, and the left side being usually larger than the right. The ex-

planation of this is to be sought in the fact that the animal to a considerable extent lies upon its right side and ventral surface. This tends to prevent growth of the disk towards the right and in front and to encourage it towards the left and behind.

The growth of the plates exhibits certain peculiarities. In a circular plate symmetry of growth would be equal increment at all points along the circumference; in a square plate equal increment on all four of the sides; and in a rectangular plate equal increment on the two sides and also on the two ends, but the increment at the ends greater than that at the sides. The plates of *Chelyosoma* do not grow in this symmetrical fashion, parallel sides of a plate not showing equal increment. The asymmetrical growth of the individual plate is connected with its relation

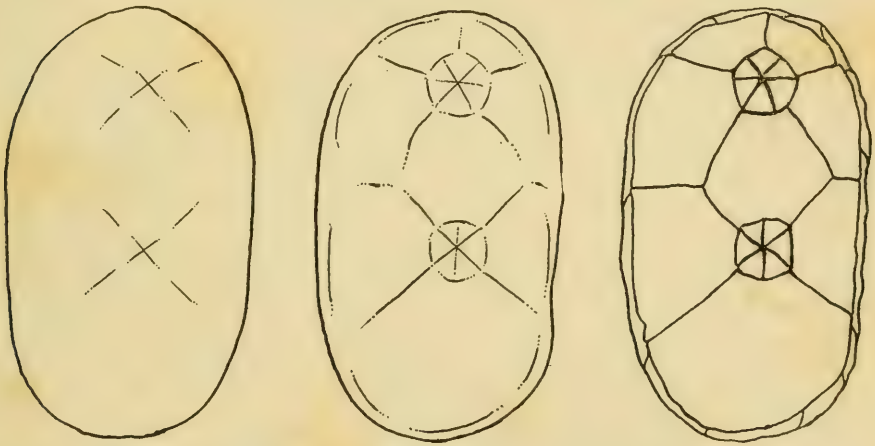

FIGURE 1—SCHEME SHOWING GENESIS OF PLATES IN *C. Macleayanum*

to the aperture to which it belongs. The effect may be stated thus,—the amount of growth increases with the distance from the aperture. The siphonal plates are shaped each like an isosceles triangle, of which the apex forms the extremity of the apertural lobe. The superficial growth of these plates is entirely at the bases of these triangles, that is at the base of the siphon, the tips and sides of the plates not extending. The extrasiphonal plates show greater increments on the sides next the margin of the disk than on those next the siphons. There is, however, considerable variation in the relative amounts of the yearly increments on the opposite sides of a plate, one side growing more, relatively to the other side, in one year than in another.

CHELYOSOMA PRODUCTUM, Stimpson.

We have had for study a large number of specimens of various sizes from the coast of British Columbia. In this species the body is not flattened or depressed but is elongated in a direction making a considerable angle with the disk. As a result the latter is more symmetrical than in the preceding species, there being less disparity between the right and left sides and between the anterior and posterior ends. The area of attachment to the substratum is small and the disk is relatively smaller in comparison with the siphons and with the whole body. The yellow layer is very thin and the test has only a slight yellowish tinge even in large individuals. The extrasiphonal plates are less distinct but more numerous than those of *C. macleayanum*. They also show greater variation, but their symmetry and presumed mode of formation are the same. The atrial extrasiphonal series contains ordinarily

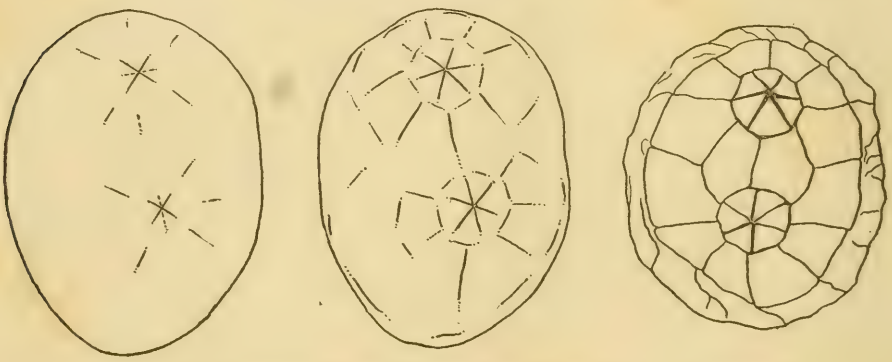

FIGURE 2—SCHEME SHOWING GENESIS OF PLATES IN *C. Productum*

eight, that is, twice the number of plates that is to be found in the same series in *C. macleayanum*, and this condition is very evidently the result of each plate dividing into two, as is most clearly seen in the case of the central plate (Pl. I, fig. 2). The oral extrasiphonal may show the same condition, although frequently the division is carried a step further by the original anterior plate being divided into four, making ten in all. In respect to this tendency for the anterior end to take the lead in subdivision of the plates, the two species agree. Text fig. 2 gives the presumed mode of origin.

In the larger individuals of this species definite lines of growth are to be seen on the plates (Pl. I, fig. 2). Bancroft has noted and figured these, but has attempted no explanation of their presence, though stating that they are present only in the larger individuals. In our material we have found by reference to these lines that there are very many in

their first, nineteen in their second, three in their third, and one in its fourth year. If this material is representative the death rate is extremely high compared with that of *C. macleayanum* on the arctic coast of Alaska.

The average length at the first winter period of the disk of seven individuals from Departure bay on the inner coast of Vancouver island that were more than one year old, was, as determined by calculation from the relative position of the first winter line or check, 9 millimetres, the range being from 6.6 to 10.5 mm. Eleven individuals from Ucluelet on the outer coast of Vancouver island had an average length for the first winter period of 12.6 mm., the range being from 6.7 to 15.1 mm. This difference may be significant, as the inner coast of the island supports a colder water fauna than does the outer coast.

The few individuals of more than two years in age that have been available, exhibit a marked decrease in growth after the second year. We may instance the oldest one obtained, which had a disk 26 mm. long. The increase in the disk in successive years was, as calculated, 10.2, 8.8 4.1 and 2.9 mm., of which the last increment may not have been complete. The growth of *C. productum* may, therefore, be considered as slight after the second year.

It may be noted that also in this species the amount of growth increases with the distance from the apertures, not only circularly with the aperture as the centre, which is a necessity if the disk is to remain flat when contracted, but also radially. In one individual, of which the disk is shown in Plate I, fig. 3, a very peculiar growth was noted. At least during the second year all of the extrasiphonal plates grew relatively much more along their right than along their left borders. What factor may have produced this we are unable to suggest.

It may be noted that the young individuals less than one year old had by July or August nearly completed their full growth for the year as calculated from older specimens. This indicates that the season of growth is the spring and early summer.

CHELYOSOMA COLUMBIANUM, Huntsman.

The material at hand consists of a rather large number of individuals from British Columbia with disks ranging from 10 to 18 mm. in length which were collected during the summer seasons of the years 1908 and 1909. The body is almost as depressed as that of *C. macleayanum*, and to some extent correlated with this condition there is a marked asymmetry of the disk consisting of a pronounced development of the posterior end and of the left side. As in *C. macleayanum* the disk is relatively large.

The yellow layer of the test is very thick, giving the animal, except in specimens that appear to be young, a decidedly yellow colour. The extrasiphonal plates tend to be somewhat irregular and their number is large and quite variable. To explain the condition let us take the ordinary condition in *C. macleayanum* as a starting-point. This explanation of the origin of the plates is illustrated in text figure 3. We have seen that in the oral siphon the two lateral plates of the four primary ones are divided by a *transverse* cleft, making six in all. In the extrasiphonal oral area, on the contrary, the primary four plates are increased in number, not by a transverse division, but by a longitudinal or *median* division, which affects only the anterior plate, making a total of five. In *C. columbianum* this median division affects also the posterior member of the oral extrasiphonal series, that is the central plate, giving a minimum number of six plates, (as seen in Plate I, fig. 4), which agree in position

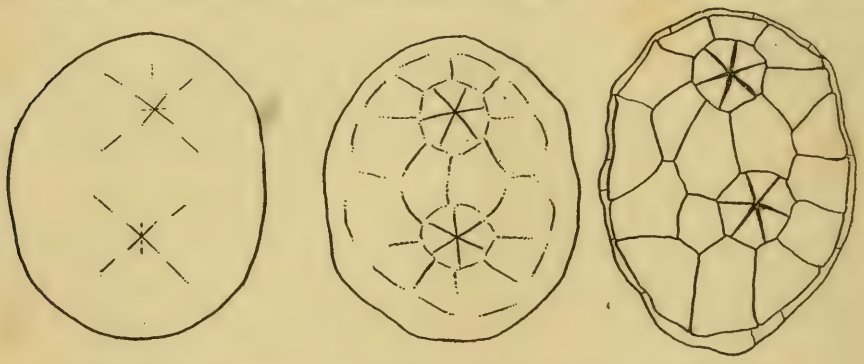

FIGURE 3—SCHEME SHOWING GENESIS OF PLATES IN *C. Columbianum*

with the six plates of the atrial siphon. Usually there is further division, which curiously enough is more apt to affect the two anterior plates than the individual lateral plates of either side. Of the anterior plates the right is more frequently double than is the left. In the extreme condition there are ten plates in this series, derived from the original four plates as follows, anterior, 4; right lateral, 2; left lateral, 2; posterior (central), 2; which is the condition in *C. productum.*

In the atrial siphon the original four plates have become six by a *median* division of the anterior and posterior plates. In the extrasiphonal series the original four are increased by a *transverse* division of the lateral plates, which may affect only the right lateral. If both are divided, we would have six, but the anterior member of the series (the central plate) is common to both oral and atrial areas and has already been divided in its relation to the oral area, so that we have seven as the usual number of extrasiphonal atrial plates (Pl. I, fig. 4), that is one less than in *C. productum.*

The number of extrasiphonal plates is commonly increased by divisions giving plates that do not touch either siphonal area. This affects the parts of the disk most distant from the apertures, chiefly the middle of each side, where such additional plates are occasionally to be found in the two preceding species. In *C. columbianum* this process is continued posteriorly, chiefly on the left side. Such divisions take place circularly with the apertures as centres and are therefore in series with the grooves separating the siphonal from the extrasiphonal plates and with that limiting the disk itself. Occasionally this process results in a division of one of the central plates, thus somewhat definitely separating the two extrasiphonal areas.

We have been unable to find lines of growth on any of the plates in any of the individuals examined. It is quite unlikely that large yellow individuals obtained in June, 1909, can have been less than one year old. We suggest that growth in this species is limited to the first year. We did not obtain any very small individuals, but several which had only a faint yellowish tinge were obtained in August, and these we consider to be less than one year old, that is the product of the same year. They were nearly as large as the strongly yellow individuals. We conclude, therefore, that this species completes its growth during spring and early summer, that the yellow layer is not fully formed until a much later period, and that growth does not take place after the first year.

CONCLUSIONS.

Lines of growth shown by the plates of *Chelyosoma* may be used for the determination of age and for the calculation of growth in view of the facts, (1) that the outer yellow layer of the test is hard and rigid, (2) that it increases in extent by additions at the margins of each plate, and (3) that it continues to thicken at the turned-in margin after the growth for the season has been completed, thus marking the winter outline of the plate.

C. macleayanum in the Arctic waters of Alaska shows a well sustained growth for more than four years.

C. productum in the waters of southern British Columbia grows vigorously in each of the first two years of its life and continues to grow, but much less vigoroulsy, beyond the third year.

C. columbianum in the waters of southern British Columbia grows rapidly during the first year and apparently not thereafter.

The comparative rate of growth of the parts of the disk of *Chelyosoma* is related to the apertures, and obeys the law that growth both radially and circularly increases in amount with the distance from the apertures.

The test in the neighbourhood of the apertures is divided more or less regularly by grooves into series of plates in the following fashion. A circular groove delimits each siphonal area. An elliptical groove delimits the disk, of which the apertures are the foci, and which is formed, outside of the siphons, by the fusion of the extrasiphonal areas of the two apertures. Occasionally the two extrasiphonal areas are imperfectly divided by a groove half-way between the siphons. Occasionally the extrasiphonal area is divided very imperfectly into an inner and an outer series of plates, this affecting chiefly the atrial part and the left side.

The radial divisions from each aperture take place primarily in the two diagonal planes, giving four parts. Subsequent division takes place in the median plane in the atrial siphonal and the oral extrasiphonal area, and in a transverse plane in the oral siphonal and the atrial extrasiphonal. The extrasiphonal areas may show further division, in the median plane in the case of the atrial area, and in the transverse plane in the case of the oral. The oral may show additional division on either side anteriorly in planes midway between the median and the diagonal. While circular division of the extrasiphonal plates takes place to a greater extent in the more extensive atrial end and left side of the disk, radial division advances further in the less extensive oral end and right side.

EXPLANATION OF PLATE.

Plate I.

Figure 1. *Chelyosoma macleayanum*. Disk of individual from Arctic Alaska, in its fourth year. × 2.

Figure 2. *C. productum*. Disk of individual from Ucluelet, B.C., in its second year. × 2.

Figure 3. *C. productum*. Disk of individual from Ucluelet, B.C., in its second year. × 3. Second year's growth of plates predominantly on right side.

Figure 4. *C. columbianum*. Disk of individual from Departure Bay, B.C. × 3.

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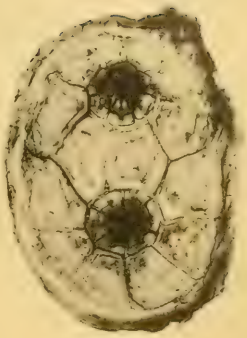

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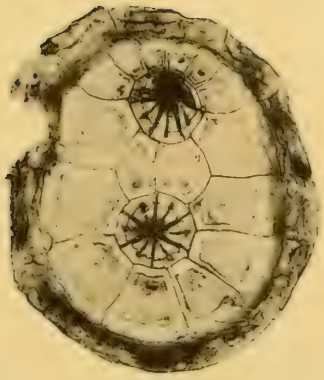

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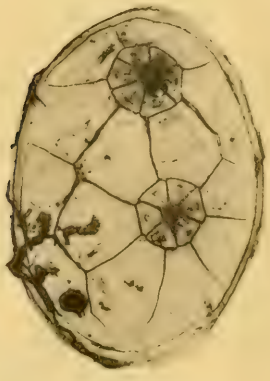

4

HUNTSMAN ON CHELYOSOMA.

HELIOTYPE CO. BOSTON

THE POSSIBILITIES OF THE OIL RESOURCES OF CANADA.

By D. B. Dowling.

The mobility of liquid fuel introduces into the question of a survey of oil resources many problems quite foreign to the study of the coal measures. Certain formations indicate the probable presence of either of these resources, and generally the formations carrying oil precede in time of formation those carrying coal. The influence of earth movements and the introduction of compressive strains generally harden and consolidate the coal, but have the effect on the semi-fluid matter of increasing its fluidity, and so hastening its segregation into pools, or even of facilitating its escape from the beds through fissures or along the porous beds to natural outlets. The survey of these resources, in addition to the superficial mapping of the areas, include also studies of the physical condition of the beds presumed to be oil-bearing. As already suggested, excessive fracturing and disturbance indicate a possible waste, whereas gently flexed beds may provide many structures favourable for the retention and collection of the oil.

The study of our probable fields must consequently include the outlining of the deposits in which oil has been found in other parts of the continent, a careful study of the general structure with the view of eventually eliminating those portions from which the reserves may be deemed to have been drained, and selecting for prospecting those parts which give some promise of success. The term prospecting is not applied here in the same sense in which it is used when referring to the search for other minerals, but generally involves the actual drilling of wells to test the measures, which should be undertaken only after the preliminary examination outlined above.

The granites of the Canadian shield represent parts of the older continent; upon this rest the stratified beds, in which are entombed the remains of the passing life of the earth. Much of this represents the life in the sea, and the great mass consists of the simpler forms. These appear to have furnished the material which is altered to oil, while the plant life in the marshes and lagoons and near the shores appears to have been preserved as coal. Large areas of these rocks have been stripped from the granite base, leaving bare the "Canadian shield", which must be excluded from our possible oil fields, and other areas are broken, folded, and faulted, so that careful examination will eliminate parts where it would be useless

to bore. In these areas it may prove, however, that the faulting has exposed to ready mining shales that have absorbed or retained the oils or material that can be distilled into oils.

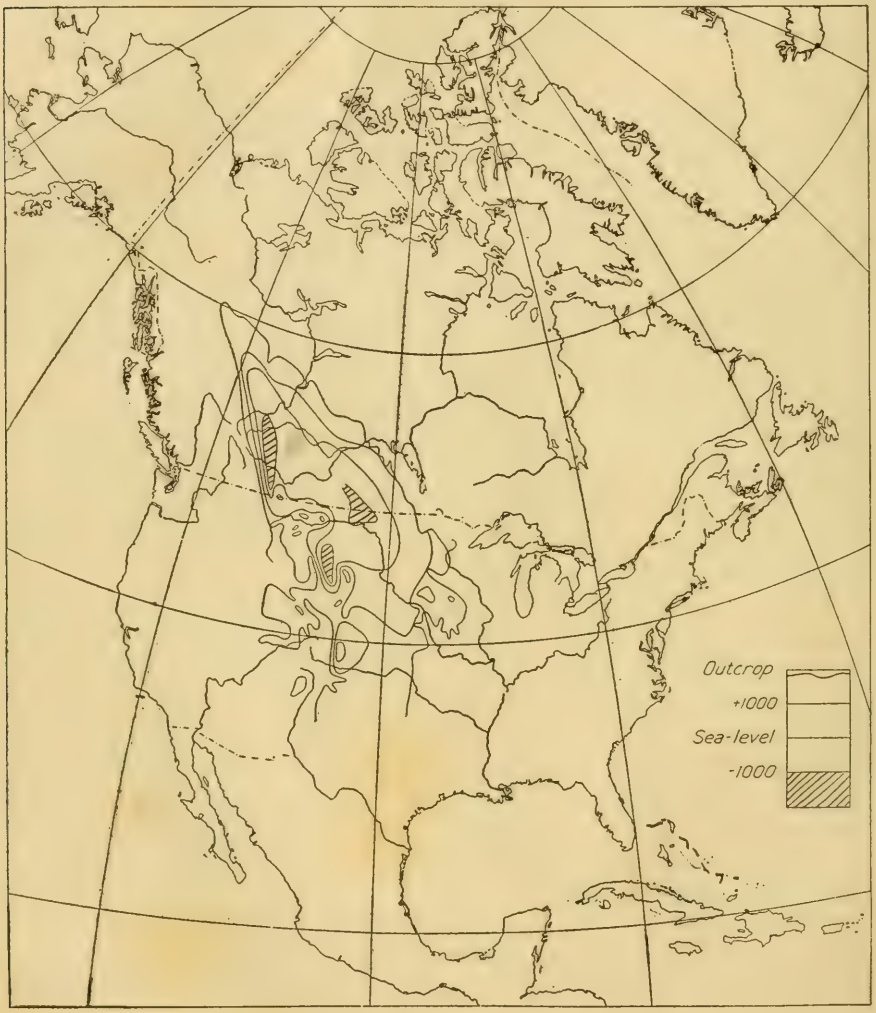

FIG. 1—THE CRETACEOUS BASIN

OIL FORMATIONS.

In the United States oil is found in formations of Palaeozoic, Mesozoic, and Tertiary ages. In the Palaeozoic, oil formations are found beneath the Coal Measures in rocks whose ages range as far back as the Cambro-Silurian. The greater accumulations appear to be in the porous

beds of the Devonian. In the Mesozoic formations, porous beds of the Upper Cretaceous are productive in Wyoming. Similar strata have been prospected in the Canadian fields, but with little success. Oil has been

Great fault blocks dropped
Rocks exposed in this area older than oil bearing beds
Folded crushed and invaded by intrusives
Continental stresses have not proven destructive to possible oil bearing beds in this area
Folded and intrusives

FIG. 2—FRACTURE ZONES

found in Canada in the Lower Cretaceous, the horizon being approximately between the coal-bearing Kootenay, and the western representative of the Dakota rocks. The Tertiary formations of the Pacific coast that represent marine deposits have proved rich in oil in the California fields. Very small patches of rocks of this age are found along the Canadian coast, but these so far have not proved commercially valuable

PALAEOZOIC FORMATIONS.

As these formations were deposited about the old continental nucleus, during the period of its greatest depression, they now form, or underlie, a large part of the present surface. They have, however, in large areas been stripped from the old continent during the long period through which they have since been subject to erosion. In the subsequent changes of elevation, the differential movements were impressed on the beds in the form of undulations, thereby facilitating the collecting of any contained oil in pools, but where the stresses were very great the deformation reached the proportions of destruction.

Of the original measures surrounding and partially covering the ancient continent, not only has a large part been removed by denudation, but great zones are fractured, folded, and crushed. From these zones much of the broken material has been removed. Blocks that have been elevated have become drained of any possible oil, and the folded and crushed areas in consequence rendered of very slight value as oil fields. Where, however, the oil has not migrated to the coarse porous beds or sands, but is retained in the shales, the fracturing may be an aid to their exploration.

The fracture zones of the continent are, for the Palaeozoic sediments, the limiting boundaries of the oil fields, although within these zones small areas may be found with indications of oil. See Fig. 2.

FRACTURE ZONES.

Two main lines of intensive crushing and deformation are indicated. The greatest follows the line of the Cordilleras through the length of the two American Continents. In Canada this belt of weakness or deformation, which affected the Palaeozoic sediments, is a broad one, and is represented by the Eastern Belt of the Canadian Cordilleras. In this, the zone in which accumulation of oil might have been looked for, is entirely destroyed, and the blocks that are elevated and exposed in the eastern edges of the Rocky Mountains appear to be already drained.

Near the Atlantic coast, lines of elevation and fracture show the effect of great lateral pressure exerted at various times. The lines of weakness are not continuous nor essentially parallel, so that the band of deformation contains within it areas not badly crushed and in some of these, small showings of oil have been found. The disturbed measures show large quantities of oil-shales, and the potential value of the Maritime Provinces for the production of oil would seem to lie in these oil-shales.

Fracture zones are found in the northern or Arctic regions. These represent what appears to be normal faulting and have made their

impress on the topography mainly by the subsidence of great blocks as in Baffins Bay and Davis Straits.

DENUDED AREAS.

A large portion of Canada forms what is referred to as the "Canadian shield". This is an area largely denuded of any covering of Palaeozoic beds that may have been deposited on the pre-palaeozoic continent. It now forms an undulating or mammillated surface of crystalline or highly metamorphosed rocks.

POSSIBLE OIL PRODUCING AREAS. EASTERN MARITIME FIELDS.

Between the fracture zones of the Atlantic border there are a few areas which suffered but moderate deformation. The largest is in New Brunswick and only a slight production of oil has been obtained. In the eastern part of Quebec in the Gaspe peninsula the presence of oil seeps has induced the spending of large amounts in prospecting. The attempt has not been successful in a commercial sense, owing no doubt, to the small area of the fault blocks. In Nova Scotia only one oil seep has been reported. In these areas the hope for oil production seems to lie in discoveries of oil shales rich enough for profitable distillation. Promising fields of oil shale have been found in Nova Scotia and New Brunswick.

ST. LAWRENCE FIELDS.

West of the broken area referred to above a narrow basin is found embayed in the St. Lawrence valley between the Archaean area and the northward continuation of the Appalachian Mountains of the United States. In this basin sediments of the lower oil formations are found, but as the area was isolated probably as early as Carboniferous time through a period of elevation, and is of comparatively small size large accumulations of oil are not expected in it.

ONTARIO FIELDS.

The basin lying to the west of the St. Lawrence basin extends westward to the Rocky Mountains and the sediments have suffered only slight warpings so that the accumulation of oil formed very large pools. This basin has been for a long time the great oil field of the United States. In Canada the outer rim is found in Ontario where a steady production has been maintained for a long period. This has steadily declined, and many of the pools have been nearly drained. The demand for oil has revived the interest in further exploration. New pools have been located, and deeper drilling or drilling to lower horizons indicates that possible pools exist in these horizons.

WESTERN BASIN.

The northward continuation of this interior basin follows the western edge of the Canadian shield. In Dakota and eastern Montana and northward through the prairie provinces of Canada it assumes a definite basin form, in which is found above the Palaeozoic oil beds the Cretaceous deposits which provide both coal and oil for the western states and very abundant coal reserves for Canada. Owing to the great structural depression in the central part of the continent to which the Palaeozoic beds conform, the areas available for oil prospecting consist mainly of part of a somewhat narrow rim along the eastern side of the basin that is in a way limited to the part which projects above sea level.

This assumption of a boundary to the production area is a tentative one based on the fact that farther into the basin the depth of Cretaceous sediments to be pierced becomes so great that drilling operations are very expensive and very difficult.

The re-appearance of the Palaeozoic rocks to the west of the basin is generally in the form of fault blocks overthrust on the newer sediments, and the actual western rim is deeply buried. There may be places where these rocks could be reached outside of the fractured zone of the mountains, but a great thickness of Carboniferous and early Mesozoic deposits here overlie the Devonian, and experience in the American field points to the greater value of the Cretaceous beds which overlie them, as oil containers. Besides the surrounding rim, it may be of interest to note that although there is little evidence of abrupt changes of slope or of structures favourable to the occurrence of probable oil reservoirs, one terrace or broad anticline can be traced on the eastern slope of the basin from the northern point southeastward about parallel to the mountains. It is probably more sharply defined in the measures near the surface, than in the Palaeozoic, and is discussed as affecting the Mesozoic deposits. It is joined at almost right angles by an uprise, which extends northeasterly from the Bow Island anticline, which rises to the south to join the Sweetgrass arch, a structure running into Canada from the uplifted and intruded area of northern central Montana. This ridge structure which crosses the basin may be too deeply buried for present prospecting, but its presence will be of interest should the Palaeozoic rocks of this basin prove at any place to have oil pools.

NORTHERN BASINS.

No exact dividing line is drawn between the Western basin and those basins to the north. The syncline of the Western basin flattens to the north and the amount of depression in front of the mountains lessens.

A large area is underlain by Devonian beds that exhibit a very slight degree of folding. This area extends from the Rocky Mountains eastward to the granite areas of the Canadian shield. The relief is generally low and includes the Mackenzie valley. The disturbance which is marked by the upthrust of the Rocky Mountains extended into the area but with lessening force. A major fold or break crosses the valley from south to north, dividing it into two distinct basins differing in structure. The area east of this fold and extending to Great Slave lake and Great Bear lake is a plain bounded on the south by the edge of the plateau built up of Cretaceous sediments, on the west by the Nahanni mountains, and on the northeast by the mamillated surface of the Archaean rocks. The outcrop of the middle Devonian sediments on Slave lake shows several oil springs. The rocks dip slightly to the southwest and seem to offer a large field for prospecting.

To the west of the dividing fold, noted above as the Nahanni Mountains, and along the lower part of the Mackenzie valley, the sediments show a series of strong folds and oil seeps are quite common. In both these fields there seem to be great masses of oil-saturated shales and porous dolomites from which oil is expected to be obtained by drilling. Should the drilling of the favourable structures not prove the presence of a fluid oil in commercial quantities, the reserve of oil in the shales should in itself be of great importance.

ARCTIC ISLANDS.

The northward continuation of the strata exposed in the Mackenzie valley is exhibited on several of the outer islands of the group. The structure of the islands exhibits very little of the compressive strains of the continent. Normal faulting probably is indicates as being the basis of the geographic features. The blocks which form the islands show the beds dipping at slight angles to the northwest and north. In rocks of Carboniferous age, shales or cannel coals which appear to have a value as oil shales have been found on Melville island. The measures in which these occur are thought to thin out toward the east, as on Elesmere island they appear to be wanting. The rocks there exposed are mapped as Triassic overlying Devonian.

JAMES BAY BASIN.

An area of Devonian rocks to the south of the bay forms a small prospective area in which oil or oil shales may be discovered.

MESOZOIC FORMATIONS.

Heavy oil has been found in the deposits of Mid-Cretaceous age. These form the lower members of the series of deposits which have filled the basin described as the Western basin of the Palaeozoic formations. The first or earliest of Mesozoic age are Jurassic marine sediments which were spread over the western part; following these are Lower Cretaceous fresh water and shore sediments with coal, which occupy the western margin and are found also in the broken area of the mountains. Farther into the basin the succeeding marine sediments followed as the depression extended eastward. In the sands representing the shoal water of this advance and in the shales associated with the sands of the western part at least, accumulations of gas are found with occasional signs of oil. The sands of the formation intermediate between the Lower Cretaceous, and the shales and sands of the Upper Cretaceous, and probably partly included in the lower part of the Colorado formation, so far as now known are the principal oil bearing beds. These have been pierced in several bore holes in Southern Alberta and heavy oil or asphalt was obtained which is assumed to be the origin of the distillate found in the foothills. In the northern margin of the basin these deposits form the Tar sands of the Athabaska. Attempts are being made to find, at a distance from the outcrop, areas where this oil will be fluid enough to provide commercial oil wells. The borings at Peace river are for this purpose. An outline of the basin is shown in Fig. 1.

In Manitoba the shales of the upper part of the Colorado formation are impregnated with oil. These oil-shales are found exposed in the Pembina river valley and from well records are found to underlie a large part of the Pembina escarpment. Another exposure is on the north side of the Pasquia Hills in the northern part of the province. These although of great thickness have not been found to be rich enough in oil for present exploitation; seven gallons of crude oil to the ton being found in samples taken at random and about 22.5 lbs. of sulphate of ammonia.

The present production from the Cretaceous beds is principally in the foothill area southwest of Calgary where a distillate of the heavy oil of the bottom of the basin, after traversing the porous beds of the western uprise is condensed and trapped in the outer fold. A light oil, nearly a gasoline, is found in the wells and the accompanying gas also yields gasoline. The field produces from forty to sixty barrels of gasoline and kerosene per day. Light oil has also been found in the mountains near the International Boundary in what appears to be an overthrust of Cambrian rocks on Cretaceous and is also probably a distillation product. On the eastern side of the great Alberta basin heavy crude oil is obtained in Peace river valley. This appears to be from the same horizon

as the tar of the McMurray beds on the Athabaska. Showings of oil have been reported in the Viking gas field east of Edmonton, and south of the Bow Island gas field heavy oil is reported in two wells in the southern part of the province.

TERTIARY FORMATIONS.

During the later history of the continent and after much of the deformation and erosion of the older oil formations, beds of Tertiary age were deposited along the western edge of the continent. Those found in the interior are generally of continental origin and what carbonaceous material they contain appears to have been altered to coal or in places to a very heavy asphalt. The more fluid hydrocarbons are at present supposed to be associated with the beds formed near sea level including those of the west coast and possibly some of the Tertiary of the extreme north on the Arctic islands.

The rocks of the valley and coast of California have been found to contain very large stores of oil. Small exposures along the coast northward and in the depression occupied in part by the Straits of Georgia have been partially examined, so far with little success. In the delta of the Fraser river boring is now proceeding, but the deposits are very thick and the sandy nature of the measures suggests that the oil may be widely dispersed rather than gathered into pools.

RESEARCH IN ENGINEERING COLLEGES

By A. E. KENNELLY

Professor of Electrical Engineering, Harvard University, and Director of Electrical Engineering Research, Massachusetts Institute of Technology.

Mr. President and Gentlemen of the Royal Canadian Institute:

It is now nearly a year (51 weeks), since one of our well known electrical engineers, Dr. Frank B. Jewett of New York, read a paper before you on the subject of "Industrial Research" (13). I think you will agree with me that it was a very interesting presentation. Two of its main propositions may thus be stated: (1) that industrial research, properly directed and intelligently conducted, is capable of realizing great industrial advantages in any country, and (2) that such results can best be brought about by close co-operation between the industrial interests of that country and its higher educational institutions, since from the latter must come the young men qualified to build up industrial research.

Concurring cordially with these propositions, the writer ventures to present to you in this paper a contribution to the same subject of research, but from the standpoint of the engineering college. It should be understood, however, that the writer has no authority to speak officially in this matter for the engineering colleges, or for any of them. He mer ely offers his personal views, in the hope of stimulating thought and discussion upon these topics among scientific, professional and business men. It is the writer's belief that organized research is of enormous importance to all nations, and that the benefit properly realizable by any one nation in this direction must inevitably share itself among all the nations of the globe. What is needed, in order to secure properly conducted research, is not so much endowment or material resources, but rather a clear and widespread understanding and agreement upon what research can accomplish, and upon the right means of securing the best national results through its means. We need, at the outset, intellectual rather than financial concurrence; because, if leadership in public opinion can be favourably impressed with the benefits likely to accrue in the pursuit of research, material and financial support may be expected to follow.

In each and all of the industries of commercial life, progress in production has always been developed by the search for improvement. If

we define industrial research as scientific investigation economically directed towards improvements in production, we may say that industrial research has been more or less actively employed in the civilized world for centuries. Discovery and invention have, in all ages, fostered existing industries and developed new ones. Consequently, there is nothing new in the broad principles of industrial research. The novelty in recent industrial research lies in the emphasis upon, and the organization of, the process.

Until machinery came to dominate the processes of production, manufactures of all kinds depended mainly upon the manual skill of the workman. This skill had to be imparted from master to apprentice, from the experienced to the inexperienced. There was a charm of individuality in good workmanship under those conditions, which is now very difficult to retain in the modern factory system; but, in compensation for that loss of manual dexterity and of artistic production, we have gained the power of greatly increased rapidity and uniformity of output. Under the old system of hand work, there was but little opportunity for the application of science to production. Under the modern system of rapid mechanical work, scientific methods are constantly capable of effecting economic improvement. It is now generally recognized that the scientific method not only can be made to pay; but that no industry is safe from competition unless maintained by perpetual good management and perpetual scientific study.

In Great Britain, the manufacturers have always maintained a reputation for very conservative action in regard to production. The superintendents, foremen and workmen were proud of their experience and practical training. Very few of them, in times past, received any scientific or technical training. On the other hand, the British scientists of a generation ago rarely came into contact with the industries. Their work was largely confined to the college lecture rooms and laboratories. Between the factories and the colleges, a great gulf was fixed. The men of affairs naturally often regarded the scientists as unpractical. The scientists often regarded the manufacturers as untutored. Nevertheless, by the very necessities of the industries, scientific processes slowly filtered into the factories, in spite of the disjunction between the engineers and the factory men. Gradually, the colleges and the works began to understand each other, through intermediaries. At first, the technical colleges had great difficulty in finding even the lowest positions for their graduates in the industrial establishments. Slowly, it began to be recognized that the young college men could be trained by practical experience into valuable industrial designers, superintendents and executives. The world war has, moreover, completely changed the relative aspects of

science and industry in Great Britain, as elsewhere. It seems likely that, in future, the mutual understanding between them will be much better, to the probable great advantage of both.

In Germany, about the middle of the nineteenth century, the attitudes of science and industry to each other were very similar to those that existed in Great Britain. But in Germany, the government influence and control, in both the technical colleges and in the industries, were more extensive than in Great Britain. Consequently, the German government compelled a closer degree of co-operation between them than would have been likely to occur under free conditions, such as those which existed in England. The German government soon realized the great advantages which the union tended to bring about. Highly trained graduates of technical institutions were set to work in dyeworks, chemical industries and factories of all kinds, working out, under the direction of business men, new or more economical processes of production. The result was, as we all know, that Germany acquired, before the war, predominance in one industry after atnoher, to the displacement of her trade rivals.

In North America, the relations between science and manufacturers, during Colonial days, were very similar to those which existed simultaneously in Great Britain. There were, however, several influences at work on this continent divergent from those of Europe. In the first place, the immigrants here must, by the very fact of their transfer across the Atlantic ocean, have possessed a certain degree of mental restlessness, on the average, above that possessed by those of their families who stayed behind. In other words, the more restless and active spirits tended, on the whole, to migrate, while the more calm and placid spirits tended to remain in Europe. This artificial selection of the more vigorous, aggressively nervous, and restless individuals, from among the European nations, has continued uninterruptedly for some three hundred years, along with the automatic sequestration of that more restless group in the North American continent. Unless, therefore, these qualities are not transmitted by inheritance, we might expect to find that the North American stock, although of very mixed original nationality, should possess, on the whole, a marked excess of vigour, enterprise and mental restlessness over the average found in their European congeners. It will probably be admitted that these differences are sufficiently marked to be readily, if not saliently, perceptible.

This mental restlessness of the North American people, acting in conjunction with the relative scarcity of available labour, has led them to continued efforts towards new, different and better material production, especially in the direction of machinery and machine-made

articles. It has also helped to break down the barrier between the sciences, as taught in the schools, and production as learned in the factories. The result was that there has been, in the past, more extensive co-operation between the colleges and the factories, than could be brought about in ante-bellum Europe, outside of Germany. Instead of having to persuade the factories to employ the technical-college graduates, the factories have usually besought the colleges for young graduates to train up in their employ. This has brought about a very rapid rate of development of production in this country during the last few decades.

The war has revealed very clearly that all processes of large-scale production are essentially of the same nature as engineering, and that if engineering consists in applying the forces of nature to production, with the greatest economy and effectiveness, it becomes desirable that everyone who is engaged in production should be trained, more or less, in economics and engineering, to an extent depending upon the nature and responsibility of his share in the work.

The scientific departments of universities in every country have always carried on two functions: teaching and learning. The teaching is the dissemination of the knowledge already acquired. The learning is the acquisition of new knowledge by research. Scientific research has always flourished under the auspices of universities, partly owing to the habits and traditions of academic surroundings, and partly owing to the intellectual stimulus provided by scientific associates. It is not incumbent upon the purely scientific departments of universities either to carry on industrial research, or to supply graduates for that purpose. A student who has graduated in physics may be well equipped to undertake industrial research, if he has the aptitude and inclination; but there is so much important work to be done in unapplied physics, that the research undertaken by departments of physics is likely to be of greater value if it is restricted to enlarging the world's knowledge of natural law. Even from a purely utilitarian standpoint, the needs of industry are more likely to be furthered by diligent research in pure physics, than by enlisting all scientific research in industrial applications.

It is, however, incumbent upon the technical colleges, and engineering schools of universities, to foster engineering and industrial research. They can do this in several ways, and they are already engaged in these directions to a greater or less extent; namely (1) carrying on research in applied science, in their own laboratories, (2) training industrial researchers, as well as constructors and engineers, (3) carrying on teaching in conjunction with industrial establishments.

It is possible for the technical colleges to undertake a certain amount of industrial research in their own laboratories; but, as a general rule,

it is undesirable that this practice should be followed to any considerable extent. In the first place, the amount of industrial research work taken up by these colleges should not, in any case, be so much as would interfere with the regular use of the laboratory equipment for teaching, and, in the second place, the psychological influence of industrial research in a college laboratory is undesirable, and is opposed to the spirit of a public institution for teaching and learning. Industrial research differs from research in applied science only in its ethical purpose. Research in broadly applied science is conducted for the benefit of all industries and all nations alike. Insofar as it leads to useful results, those results are at once opened to the instructors, the students, and the engineering world. On the other hand, industrial research is conducted in the immediate interests of an industry, and those interests may properly require that any useful results attained should be kept secret, for the more exclusive benefit of the corporation that has incurred the expense. No corporation would be likely to undertake strictly industrial research, unless it believed that the attempt would pay. The successful results would probably not pay if disclosed forthwith to competitors. Consequently, any considerable amount of strictly confidential industrial research, carried on in a technical college laboratory, introduces an air of mystery and secrecy, which reacts unfavourably upon the intellectual atmosphere of the institution. The purpose and history of academic institutions has always been to make knowledge open to all earnest enquirers on equal terms. "Thou mayest know what I know" is the motto of every educational establishment worthy of the name. Among all the embargos, trusts, monopolies and esoteric associations of all time, it is doubtful if any college or institution of learning ever established a barrier to the interchange of knowledge within its walls, and among its own members, whatever may have been its relations to the outside world, as, for instance, among the Pythagoreans.

It is, therefore, desirable that confidential industrial research should be carried on, as far as possible, in laboratories outside of the technical colleges. These colleges can, however, assist in finding the right men to undertake such work, either from their own staff, student body, alumni, or from their knowledge of other persons in the technical world. There can be no harm in the teaching staff taking part in industrial research outside of the colleges, provided that such work does not take up too much time and interfere with the regular work of teaching.

On the other hand, it is eminently desirable that the technical colleges should carry on applied-science research in their laboratories, partly for the benefit of those colleges, by spreading their reputation for scientific achievement, partly for the benefit of the teaching staff, by enabling

them to learn more and teach better, and partly for the benefit of the students, by giving them the opportunity of gaining habits of research, especially for such as have aptitudes or inclinations in that direction.

The ordinary technical college course, leading to a bachelor's degree in engineering or applied science, lasts four years, and is usually of such a nature that there is very little room for options or studies deemed unessential thereto. Nearly all the courses of study are prescribed from beginning to end. It is therefore generally admitted that, except perhaps for the experimental work pertaining to a bachelor's thesis, there can be very little opportunity for a student to undertake research during the usual four years of required study. Moreover, the majority of students in the technical colleges, and working for a degree in applied science, are more interested in the fields of design, construction, operation, administration or business in production, than in research or investigation. The men who have aptitude for research are relatively few, and it would certainly be unfortunate for industry if all the young men sought to take up investigation, to the detriment of all the other important activities of life. It is consequently desirable that those students who desire to take up industrial research as an occupation, and who manifest an aptitude for investigation, as, for example, by doing some very creditable experimental thesis work, should be given an additional year of post baccalaureate research study at their college, and preferably under the direction of the department in which their bachelor's degree was taken. This extra year of work should be encouraged by industrial fellowships, to relieve the financial burden on the student, and should lead to a master's degree. Such students are preferably to be graded as research assistants. The young men graduating in this way are likely to become valuable to the industries in carrying on industrial research; because they have not only formed habits of study at college sufficiently strong to win the bachelor's degree, but they have probably also formed habits of research sufficiently strong to win a master's degree in that direction.

The directed research work that these research assistants can do, in their year of laboratory duty, is excellent material for the advance of applied science in some particular field in which the college is interested.

It is firmly believed by the writer, and the belief is shared by many teachers of his acquaintance, that the industries will find it very much to their advantage in establishing fellowships or endowment for the extra fifth year of post baccalaureate research work above outlined. The advantage to the industries is twofold. First, a suitable supply of young graduates is secured, who are specially adapted and trained for industrial research, and second, the researches carried on by these men

in their extra year may be of such a quality in the sciences pertaining to those industries, that, without being of a confidential nature, it may conduce to the progress of the knowledge underlying them.

The type of researches carried on in any department of a technical college depends upon the directions of scientific interest in that department. It is likely to happen that the interest is determined by the nature of some works, industry or public service in the vicinity. It is not of great importance what the particular interest is, so long as it is a definite speciality or group of specialties. Each college may advantageously develop such a group. It is by developing its work along certain special lines, that a laboratory comes to be recognized for its research work. It is futile to attempt researches upon too many lines at once. Ordinarily, each member of a teaching staff interested in research, busies himself in one line, and when several individual members happen to adopt the same line, they may jointly accomplish much more than the sum of what would be their unaided individual achievements. It is advantageous to an industry, situated near to a college, to have a group of teachers there engaged in correlative applied science research.

Very recently, the Massachusetts Institute of Technology has entered into a co-operative plan with a number of industrial corporations, whereby, in return for an annual retainer, the Institute undertakes to provide certain facilities, information, and assistance to the corporations. A copy of the form of agreement is appended. A few other technical, colleges are said to have adopted similar plans. If this plan works out in practice, as successfully as is hoped, it will be desirable for many of the colleges to avail themselves of its advantages along similar lines.

Another plan which has less recently been put into action by technical colleges, but which is less specifically directed towards research, is the plan of co-operative education. It seeks to train technical men for positions in the industries, by familiarizing them with the nature and problems of those industries in periods of industrial employment alternating with periods of study in the college. This plan is carried on at Cincinnati, Pittsburg, the Massachusetts Institute of Technology, and perhaps also elsewhere. At the University of Cincinnati, where the plan has been in force since 1906, the engineering-school students spend five years towards their bachelor's degree in monthly cycles throughout the year, two weeks being in college, and two weeks in an industry, alternately (5). At the University of Pittsburg (14), where the plan has been carried on since 1911, the engineering-school students spend their first year, and also their fourth year exclusively in college. Their second and third years are spent in six-monthly cycles, three months in college, and three months in an industry, by turns. At the Massachusetts Institute of

Technology, there are optional courses in chemistry and also in electrical engineering, which occupy five years, and lead to a master's degree. After the first two years spent exclusively in college, they are carried out in cycles of alternate collegiate and industrial study. In the electrical engineering option, the student's cycle is of eight months duration, four months in college and four months at the Lynn works of the General Electric Co. During the alternation at college, the studies are of the regular kind. During the alternation at the factory, the work is mainly industrial, along a definite schedule, with certain evening collegiate studies administered by a special member of the college faculty, and also by selected members of the works engineering staff.

The faculty of the Harvard Engineering School has also recently reported in favour of adopting a co-operative option during the Junior year, including two summers, employing a four-month cycle with two months at college and two months in an industry, alternately. It is expected that this plan will receive the consent of the Harvard governing boards.

In all these co-operative technical education plans, the advantages to the student are that his pay under employment goes largely towards paying for his education, and also that he learns by experience during his college years the value of applied science to production. Although he makes no agreement with the works, if he pursues the course successfully, he is fairly sure of employment there after his degree has been obtained. The advantages to the industries are that they are thus able to obtain more rapid training for the graduate they may come to employ, and, during the formative years, to bring the men into close contact with the work and personnel of the shops. During the student apprentice period, the shopwork of the men can also be made economically effective; although it might not be worth carrying on, if the men did not elect to join the corporation after graduation. The advantage to the college is that it brings the college into touch with the industry and its problems. This also has an influence on the research work of the college.

A schedule of the above outlined electrical engineering co-operative course at the Massachusetts Institute of Technology is appended to this paper.

It seems likely that other colleges will enter into similar co-operative industrial plans of technical education.* These plans are still young, and it will be some years before the experience gained with them can be definitely determined. So far as is known to the writer, however, no

*Such plans are in force in the Engineering Departments of Columbia University and the University of Pennsylvania.

college that has yet entered on such a co-operative plan has abandoned it. In the writer's opinion, the plan forms a very valuable optional course, but is not to be recommended as compulsory; because there are technical students who do not seek to enter the industries, and who prefer to take college work exclusively. It is surely to the advantage of the community that as many different types, plans and courses of study as can economically be offered in the country at large, should be placed at the selection of the oncoming ranks of students, provided that the standard degrees offered shall represent and require substantially the same amount of time and effort in their attainment. As time goes on, it will probably be necessary for all the universities and colleges, and especially the technical colleges, to co-operate more closely with one another in the public service.

The trend of modern technical education is to fit men for improved production. This can best be brought about by cultivating close relations with the industries and productive forces of the time. This goal is in sight, but is far from being attained. The goal is very remote from the positions of the scientific schools of the ancient world, and it has taken many centuries to reach the place where society now stands in this matter. The old Greek scientific schools studied the pure sciences for their own sake, which was admirable, but they also disdained all contact with commercial affairs, which was unfortunate. The commercial and industrial worlds seem likewise to have disdained and underestimated the schools. Gradually, through the centuries, we are coming to a position where, without appreciating the great scientific universe less, we can appreciate and serve our fellows through the industrial world more.

The task of training men for industrial research is partly in the communication of a certain series of educational facts and principles as expressed in text-books and partly in the formation of certain habits and attitudes of mind. The student gains these not merely from his books and teachers; but also from his associations with the traditions of the college, and with his fellow students. It seems likely that the mental and moral habits, *i.e.*, the character formations, are more important than the fact memories. If we remember that primitive man lived in a mental atmosphere that peopled all the world about him with independent supernatural powers, and that nothing could be undertaken without satisfactory omens or propitiations of these powers, we realize that immense periods of time might be traversed by successive generations of human beings, under such a regime, without any likelihood of material progress. We also recognize in the best of us occasional vestiges of primitive mentality and superstition.

In order to realize the necessity for training the mind of the student of research in the habits of accurate observation, strict recording and careful deduction, it may be well to recall the proneness of the human mind to error in the absence of such habits. A single example may suffice. It will be generally conceded that sailors, as a class, are very keen of sense, practical in judgment, and much dependent upon the weather for the success and comfort of their daily work at sea. Sailors, as a class, are also, by general admission, at least as intelligent as any other set of men in a community. In the writer's opinion, they are above the average in this respect. It would, therefore, be naturally supposed that their general opinions concerning the weather, and changes of weather, would be particularly reliable. It was formerly a very prevalent belief among sailors, both officers and men, that the moon had an effect on the weather, or that a change in the phase of the moon either brought about or attended a change in the weather. Since the quarter changes in the moon's phase occur about 50 times a year, a sailor who had spent forty years at sea, would have been in a position to witness some 2,000 such changes, and it might be supposed that with this long series of opportunities for verifying the proposition he would speedily arrive at a correct conclusion in the matter. W. Hutchinson says, however, in his "Treatise on Practical Seamanship" (1), published in England in the year 1777, in opposing this moon theory:

> "That these changes of the weather and winds in no way depend upon the situation of phases of the moon, or the sun at the equinoxes, as they are too generally thought to do in this climate."

As soon as the statistical science of meteorology had sufficiently far advanced to show, as we all now recognize, that storms are progressive disturbances, advancing along a curved path at a rate which is often fairly uniform, at say about 500 kilometers a day, it would become fairly evident that a change in the moon's phase, which is nearly instantaneous all over the world, could not be the cause of a progressive change in the weather. Moreover, the meteorologists, after diligent statistical search, have failed to find any appreciable connection between the weather and the moon's phases or position in her orbit. The belief probably lost its hold on the minds of the scientifically trained officers, and does not seem to have been sustained in any standard work on either meteorology or seamanship. It continued, however, to hold a place among the rank and file of the mariners. Luce's "Seamanship" (2), quoting Rear-Admiral Goldsborough in 1877, says:

> "Some persons attribute influence to the moon in respect of weather, and say a change may be expected within a few days of the moon's phases. But the intervals between one and another

phase of the moon is but seven days, and 'a few' of these days *must* be a time near one phase or another. Accidental coincidences are generally alluded to influence the wind, because when they occur, they mark any event more particularly. Similar to these are the prejudices against sailing on Friday, which used to be so common."

The writer, about twenty-five years ago, found the belief to be very general among sailors, including some of the less scientifically trained officers of the mercantile marine. The belief seems to be dying out slowly, under the pressure of opposite opinion among the better informed; but it is certainly still in existence, because in at least one well known and widely distributed almanac, of this year 1920, there is a reaffirmation, with tabulated data, of the weather to be expected following a given hour of quarterly change of the moon.

The foregoing instance of a popular belief without scientific foundation, fairly widely held among intelligent folk, is evidence of the need for training the mental habits of observers who are to engage in any kind of applied scientific research. It suggests that no belief or proposition is to be accepted from the assertions of even many men, howsoever alert mentally, unless backed by methodical and unbiassed scientific evidence. In other words, we must always be prepared to prove all things, and to hold fast that which is good.

In the training of research assistants, and indeed in the training of applied-science students generally, large amounts of time and effort are wasted perennially in North America, on the cumbersome units of weights and measure in the customary English system. There are some forty-five units of measure in the tables of that system, which tables are so complex that very few persons can recite their numerical relations from memory without a mistake. Moreover, there are certain serious ambiguities in the meanings of some of these units; to wit, the terms ton, hundredweight, pound, bushel, gallon, quart, and pint. Thus, in the United States, the gallon is still the old wine gallon of Queen Anne, containing 231 cubic inches or 3.785 liters, whereas, in Canada, we have the imperial gallon, which the writer understands to contain 277.274 cubic inches or 4.546 liters, a discrepancy of over 20 per cent. On the other hand, the international metric system may be correctly said to have only two units—the meter and the gram—with additional optional names for decimal derivatives. It is only a question of time when the simple two-unit system will displace the cumbersome forty-unit system in the business of the world, just as it has already done in the scientific world. A scientific paper written in non-metric units is not a world paper, but a sectional paper. The waves of radio are believed to encircle the globe, from the emitting station to its antipodes, in about one-tenth of

a second (15), and there can surely be no room ultimately for a plurality of systems of weights and measures on a tenth of a second world. It is time that we all made a concerted effort to introduce the metric system more generally. If we wait until legislation brings about this change, we are likely to wait for an unnecessarily long time. If, however, without waiting for state or government action, we all proceed to employ the metric system in our own work, the change will rapidly be accomplished. It pays well in time and labour to carry on all college research work in the metric system, converting the results into customary units when needed.

This change to the metric system is actually taking place, as may be seen by comparing the pages of modern text books and of general literature with those of a few decades ago. It is indeed remarkable how fast the change is coming about, considering the aggregate amount of mental inertia to be overcome. It may be remembered that, according to Ball's "Short History of Mathematics" (3), it took about 150 years for Arabic numerals and arithmetic to replace Roman numerals and arithmetic in the account-books of the mercantile and business world. He says:

> "The new Arabian arithmetic was called *algorism* or the art of Alkarismi, to distinguish it from the old or Boethian arithmetic. The text books on algorism commenced with the Arabic system of notation. . . ."
>
> "Towards the middle of the fourteenth century, the rules of arithmetic *de algorismo* were also added, and by the year 1400, we may consider that they were generally known throughout Europe, and were used in most scientific and astronomical works. Most merchants continued, however, to keep their accounts in Roman numerals until about 1550, and monasteries and colleges till about 1650. . . ."

Again, Brown's History of Accounting says (4), speaking of ledgers and account books among merchants in the fifteenth century:

> "But a balance he only made once, in 1482, when the book was full. This practice of not making a general balance till the ledger was completed continued to be widespread till the seventeenth century. It is beyond all question that although about this time we find a high development in the theory and principles of book-keeping, we fail to discover a recognition of its many practical advantages. To bring the position home to us, we must bear in mind that the ledger was kept in Roman numerals."

A few of the mercantile account books of the early colonial days in New England, about the year 1640, show that the entries were still

made in Roman numerals; although the Arabic notation was then coming into universal use.

Not only did it thus take some 150 years for the present Arabic numerals to come into public and general use after the astronomers and scientists had adopted them; but the expulsion of the cumbersome old Roman numerals met with much opposition from the merchants, many of whom seem to have tenaciously resisted the innovation. Brown's History of Accounting already quoted, says, in a footnote on page 107, speaking of the change from Roman to Arabic figures:

> "In 1299 we find the guild of bill-changers of Florence forbidding the use of the 'new' figures, while as late as 1520, the municipality of Freiburg refused to accept entries as legal proof of debt, unless they were made in Roman figures or written out in words."

If, therefore, the simple Arabic numerals took 150 years to supersede complex Roman numerals in business transactions, we need not be surprised at the time it takes for the simple metric system to supersede the complex inch-bushel system. The complete change ought not to be due, on that basis of estimation, until about 1950.

Looking forward, the future of research in the engineering schools is very bright. There is likely to be good co-operation between the colleges, the industries and certain powerful co-ordinating institutions. In the United States, the National Research Council in its Engineering Division (16) is making great efforts to advance the same movement.

In its international aspect, the progress of research seems likely to foster trade, commerce, and goodwill among the nations. Nations, like individuals, tend to develop specialties in production, and their applied-science researches tend to follow corresponding lines. In times to come, we may expect that the external search for new world markets may become less keen and the internal search for improved processes of production may develop in its place.

Indeed, the prospects of research, in colleges, schools, national laboratories, business laboratories, industrial laboratories and factories, is at present so bright that there is, in the opinion of some, a danger of our being carried away too far in these directions, to the detriment of other interests and activities of a more artistic type. Production and consumption occupy a large share in human life, but they are not the *ultima thule* of existence. There are also the claims of the arts, of history, of literature, and of the spiritual world. We must hope that in the development of the material world, the aspirations of the soul shall not suffer. If we bend all our energies upon producing more things, there is a danger that our morale, as citizens of the world, may not keep pace with the production, and that we may fall out among ourselves in the

division and repartition. If, however, we can maintain a just balance between our debits and credits, our responsibilities and our dues, we may expect the whole world to become better, happier, and more livable in, through the progress of research.

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APPENDIX I.

FORM OF AGREEMENT BETWEEN THE MASSACHUSETTS INSTITUTE OF TECHNOLOGY AND AN INDUSTRIAL CORPORATION.

MASSACHUSETTS INSTITUTE OF TECHNOLOGY

CAMBRIDGE, MASSACHUSETTS.

DUPLICATE

Agreement made this ..... day of ..... 19 .....

between ....., hereinafter referred to as the Company, and the Massachusetts Institute of Technology.

The Company agrees to pay to the Massachusetts Institute of Technology a retainer of ..... Dollars,

in five annual instalments of ....., payable on the second day of January of each year from 1920 to 1924 inclusive.

The Massachusetts Institute of Technology agrees to make available to the Company, during the five years 1920 to 1924 inclusive, its library and files, and to arrange for conferences with its technical staff on problems pertaining to the business of the Company.

The Massachusetts Institute of Technology further agrees to maintain a record of the qualifications, experience and special knowledge of

its alumni that shall be as complete as practicable, and upon request to advise and assist the Company to obtain:

Information as to where such knowledge and experience are available.

Information regarding men for special problems.

Information regarding men for permanent employment.

The Massachusetts Institute of Technology further agrees to maintain a list of undergraduates who may wish positions upon graduation; to advise the Company upon request as to the records and qualifications of these men, and to arrange for interviews with them.

The Massachusetts Institute of Technology further agrees that in case the Company at any time during the period covered by this contract should have special technical problems requiring extended consultations, investigations, tests, or research work, it will advise the Company where this service can best be obtained. If, in the judgment of the Massachusetts Institute of Technology, this service can best be rendered by its staff or in its laboratories, a member of its staff shall undertake such service for a fee to be mutually agreed upon by the parties hereto.

_____

By _____

MASSACHUSETTS INSTITUTE OF TECHNOLOGY

By _____

_____

SCHEDULE OF CO-OPERATIVE EDUCATIONAL PLAN DURING THE LAST THREE YEARS OF A 5-YEAR COURSE AT THE MASS. INSTITUTE OF TECHNOLOGY

FIVE-YEAR CURRICULUM OF CO-OPERATIVE COURSE (CALLED COURSE VI-A) AT THE MASSACHUSETTS INSTITUTE OF TECHNOLOGY, LEADING TO MASTER OF SCIENCE DEGREE IN ELECTRICAL ENGINEERING.

In preparation for this curriculum students must have successfully completed the first two years of the undergraduate electrical engineering course (Course VI) at the Institute, or the equivalent.

NOTE—Figures in first column are the number of hours spent in class rooms and laboratories. The figures in the second column are the estimated number of hours preparation.

SUMMER TERM, ACADEMIC YEAR 1920-21.

	Hours	
	In Class	Preparation
Groups A and B. At Works, July 5-Oct. 2		
Machine shop training room, assembling and inspecting		
Principles of Electrical Engineering		
Direct-Current Machinery	25	50

FIRST TERM, ACADEMIC YEAR 1920-21.

Group A. At Works, Oct. 4-Dec. 31*		
Winding, Insulating and Drafting		
Principles of Electrical Engineering, Direct-Current Machinery	25	50
Group B. At Institute, Oct. 4-Dec. 22		
Principles of Electrical Engineering	42	63
Direct-Current Machinery and Alternating Currents		
Electrical Engineering Laboratory	55	
Applied Mechanics	32	63
Political Economy	32	32
Heat Engineering	32	63
Mathematics	32	63
Group B. Vacation, Dec. 23-Jan. 3, inclusive		

SECOND TERM, ACADEMIC YEAR 1920-21.

Group A. At Institute, Jan. 3-Mar. 19		
Principles of Electrical Engineering-Alternating Currents	42	63
Electrical Engineering Laboratory	55	
Applied Mechanics	32	63
Political Economy	32	32
Heat Engineering	32	63
Mathematics	32	63
Group A. Vacation, Mar. 20-Apr. 3, inclusive		
Group B. At Works, Jan. 3-Apr. 2		
Winding, Insulating and Drafting		
Principles of Electrical Engineering		
Alternating Currents	25	50

*Christmas Recess, Dec. 24-26 inclusive.

	Hours	
THIRD TERM, ACADEMIC YEAR 1920-21.		
Group A. At works, Apr. 4-July 2.		
Drafting, Designing and Meter Testing		
Principles of Electrical Engineering		
Alternating-Current Machinery	25	50
Group B. At Institute, April 4-June 18		
Principles of Electrical Engineering	42	63
Alternating-Current Machinery		
Electrical Engineering Laboratory	95	
Applied Mechanics	32	53
Heat Engineering	32	63
Political Economy	32	32
General Study	32	32
Group B. Vacation, June 19-July 4, inclusive		
SUMMER TERM, ACADEMIC YEAR 1921-22		
Group A. At Institute, July 5-Sept. 17		
Principles of Electrical Engineering	42	63
Alternating-Current Machinery		
Electrical Engineering Laboratory	95	
Applied Mechanics	32	63
Heat Engineering	32	63
Political Economy	32	32
General Study	32	32
Group A. Vacation, Sept. 18-Oct. 2, inclusive		
Group B. At Works, July 5-Oct. 1		
Principles of Electrical Engineering		
Alternating-Current Machinery	25	50
Drafting, Designing and Meter Testing		
FIRST TERM, ACADEMIC YEAR 1921-22		
Group A. At Works, Oct. 3-Dec. 31*		
Principles of Electrical Engineering		
Alternating-Current Machinery	32	64
Motor, Transformer and Turbine Testing		

* Christmas recess, Dec. 24-26, inclusive.

Group B. At Institute, Oct. 3-Dec. 17	Hours	
Principles of Electrical Engineering	63	84
Alternating-Current Machinery		
High Voltage Transmission and Power		
Electrical Engineering Laboratory	55	
Political Economy	32	32
General Study	32	32
Heat Engineering	32	63
Stationary Structures	32	53

SECOND TERM, ACADEMIC YEAR 1921-22.

Group A. At Institute, Jan. 3-Mar. 18		
Principles of Electrical Engineering	63	84
High Voltage Transmission and Power		
Electrical Engineering Laboratory	55	
Political Economy	32	32
General Study	32	32
Heat Engineering	32	63
Stationary Structures	32	53
Group A. Vacation, Mar. 19-Apr. 12, inclusive		
Group B. At Works, Jan. 2-Apr. 1		
Motor, Transformer and Turbine Testing		
Principles of Electrical Engineering		
High Voltage Transmission and Power	32	64

THIRD TERM, ACADEMIC YEAR 1921-22

Group A. At Works, April 3-July 3		
Calculating, Engineering Department		
Principles of Electrical Engineering		
Advanced Course	32	64
Group B. At Institute, April 3-June 17		
Principles of Electrical Engineering	63	84
Advanced Course		
Electrical Engineering Laboratory	55	
Materials of Electrical Engineering	21	21
Mechanical Engineering Laboratory	42	32
Hydraulics	42	84
General Study	32	32
Group B. Vacation, June 18-July 4, inclusive		

SUMMER TERM, ACADEMIC YEAR 1922-23.

Group A. At Institute, July 5-Sept. 16	Hours	
Hydraulics	42	84
Principles of Electrical Engineering Advanced Course	63	84
Electrical Engineering Laboratory	55	
Materials of Electrical Engineering	21	21
Mechanical Engineering Laboratory	42	32
General Study	32	32
Group A. Vacation, Sept. 17-Oct. 1, inclusive		
Group B. At Works, July 5-Sept. 30		
Calculating, Engineering Dept.		
Principles of Electrical Engineering Advanced Course	32	64

FIRST TERM, ACADEMIC YEAR 1922-23

Group A. At Works, Oct. 2-Dec. 30*		
Engineering and Research Assignments at Lynn and Schenectady		
Principles of Electrical Engineering Advanced Course	32	64
Group B. At Institute, Oct. 2-Dec. 16		
Principles of Electrical Engineering Advanced Course	63	84
Graduate Courses and Research	360	
Group B. Vacation, Dec. 17-Jan. 1, inclusive		

SECOND TERM, ACADEMIC YEAR 1922-23.

Group A. At Institute, Jan. 2-March 17		
Principles of Electrical Engineering Advanced Course	63	84
Graduate Courses and Research	360	
Group A. Vacation, March 18-April 1		
Group B. At Works, Jan. 2-March 31		
Engineering and Research Assignments at Lynn and Schenectady		
Principles of Electrical Engineering Advanced Course	32	64

* Christmas recess, Dec. 24-26, inclusive.

THIRD TERM, ACADEMIC YEAR 1922-23.

Groups A and B. At Institute, April 2-June 5	Hours
Business Law and Organization	36 72
Seminar, Research and Master's Thesis	324

The prescribed course is here completed with conferring of Master's Degrees at Commencement Exercises of Institute on June 8.

Opportunity for an additional (optional) summer term of Engineering and Research Assignments at the Works will be open to those students who desire to elect it.

THE MOSQUITOES OF CANADA.

By Harrison G. Dyar, A.M., Ph.D.
United States National Museum.

Mosquitoes are small two-winged flies belonging to the Order Diptera Family Culicidae, Subfamily Culicinae, and can generally be recognized by the long firm proboscis adapted for piercing. Not all mosquitoes, however, bite warm-blooded animals—there is one Canadian species which does not do so; but most of them are voracious bloodsuckers, and readily attack man. The species of the genus *Aëdes*, which constitute the bulk of the Canadian fauna, attack boldly, often by daylight, although their favourite time is the dusk of early evening. These species bite once, gorging themselves completely if given the opportunity, and then fly away. The species of *Culex*, on the other hand, which are practically absent from the northern forests, but are found in the warmer open country and especially in cities, bite in the dark of night, and if even slightly alarmed, immediately leave their victim, but only to return later. A person may thus be bitten twenty times in a single night by one *Culex*, but only once by a single *Aëdes*.

In the tropics, a number of diseases are conveyed by mosquitoes; but in Canada, there is danger of but one—malaria. This is conveyed by certain species of *Anopheles*. Of these, two species which are known malaria-carriers occur in Canada, a third known carrier may occur, and there is a fourth species which has not been tested in this relation.

Key to the Tribes and Genera of Canadian Mosquitoes.

Metanotum with a tuft of setae.....Tribe Sabethini
Genus Wyeomyia, Theobald

Metanotum nude.....Tribe Culicini

1. Wings with the second marginal cell less than half as long as its petiole.....Genus Uranotaenia, Lynch Arribalzaga
   Wings with the second marginal cell at least half as long as its petiole.....2
2. Scutellum rounded, not lobed.....Genus Anopheles, Meigen
   Scutellum distinctly trilobed.....3
3. Cross-veins tending to lie in line, the posterior close to the anterior, or mesonotum with bare impressed discolorous lines, or both,
   Genus Culiseta Felt
   Cross-veins normal; mesonotal integument uniform.....4

4. Abdomen of female blunt, with short cerci; hypopygium of male with the side-pieces curved down, or shortly projecting.....5
Abdomen of the female pointed, cerci exserted; hypopygium of male with the side-pieces prominently projecting, straight.....6
5. Wing-scales normal, narrow.....Genus CULEX Linnaeus
Wing scales distinctly large and broad,
Genus MANSONIA Blanchard
6. Abdomen of female with the eighth segment wholly retractile, nude; male harpagones with multiple terminal appendages,
Genus PSOROPHORA Robineau-Desvoidy
Abdomen of the female with the eighth segment only partly retractile; male harpagones with only a single appendage,
Genus AËDES Meigen

Tribe SABETHINI.

The mosquitoes of this tribe are almost wholly tropical. Their larvae live in the water that collects in plants, either living or dead, such as the leaf-bases of Bromeliaceae, flower-bracts of Heliconia, cavities in tree-trunks, cocoanut shells, cacao shells and palm-spathes. One species has a northern distribution, living in the leaves of the pitcher-plant, which grows in swamps.

Genus WYEOMYIA Theobald.

A large genus of tropical distribution, most of the species addicted to the water in Bromeliaceae. The genus has been subdivided into subgenera on the characters of the male genitalia (Dyar, Ins. Ins. Mens., vii, 114-142, 1919). The single species here referred to falls in the subgenus *Dendromyia* Theobald.

WYEOMYIA (DENDROMYIA) SMITHII Coquillett.

Aëdes smithii Coquillett, Can. Ent., xxxiii, 260, 1901.

A small stout mosquito with dark mesonotum and legs, the abdomen black above, silvery white below, the colours separated on the sides in a straight line. Prothoracic lobes submetallic blue. Patches of silvery white scales on the sides. A small group of minute bristles on the posterior side of the metanotum, only visible with microscope or very strong lens.

The larvae live in the water in the leaves of pitcher-plants (*Sarracenia purpurea*), passing the winter frozen up in the ice-cores. The eggs are laid on the still dry newly opened leaves, and hatch when water collects in them.

This mosquito is rarely met with except by breeding from pitcher-plant leaves. It has not been recorded as biting; but as many of the tropical species attack warm-blooded animals, this may be found to do so.

Distribution: Canada to Alabama, probably coextensive with the range of the host plant *Sarracenia purpurea*.

CANADIAN RECORDS.

Guelph, Ontario (T. D. Jarvis, Can. Ent., xxxviii, 7, 1906).
Carlsbad Springs, Ontario (A. Gibson).
Goderich, Ontario, January, 1914 (C. V. Lawson).

Tribe CULICINI.

This tribe includes the bulk of the mosquitoes, and all of those of typically northern distribution. Only a few of the lowest members live in water in plant tissues, such as tree-holes; most of the species inhabit ground puddles. The species and genera are variously differentiated. *Aëdes* inhabits temporary puddles, especially water left from the melted snow in spring, and these species have in general but a single annual generation. *Culex* and *Culiseta* inhabit pools of a generally permanent character, and overwinter as adults. *Anopheles* larvae are surface-feeders, and consequently the character of the water makes less difference in them. They have been found in all sorts of water, even in running streams, but the different species are variously restricted.

GENUS CULEX Linnaeus.

This genus is in general of southern distribution, and but few species occur in Canada. The larvae inhabit water of a permanent nature, some species taking kindly to water in artificial containers, such as water-barrels and sewer-traps. Such species are liable to be abundant and troublesome in cities.

The subgenera, defined on the male genitalia, are as follows:

1. Harpes few toothed. . . . Subgenus CLIMACURA Howard, Dyar & Knab
   Harpes with a crown of spines. 2
2. Second uncal plate present (four plates). . Subgenus CULEX Linnaeus
   Second uncal plate absent (three plates). . Subgenus NEOCULEX Dyar

KEY TO THE CANADIAN SPECIES OF CULEX.

1. Tarsi ringed with white at both ends of the joints. . *tarsalis* Coquillett
   Tarsi entirely dark 2

2. Abdomen with apical segmental white bands, *testaceus* van der Wulp
   Abdomen with basal segmental white bands.....3
   Abdomen without white bands dorsally.....*melanurus* Coquillett
3. Band at base of second abdominal segment triangular or triangularly produced.....*pipiens* Linnaeus
   This band transverse, not mesially produced.....*territans* Walker

CULEX (CULEX) TARSALIS Coquillett.

Culex tarsalis Coquillett, Can. Ent., xxviii, 43, 1896.
Culex willistoni Giles, Handb. Gnats or Mosq., 281, 1900.
Culex affinis Adams, Kans. Univ. Bull., ii, 25, 1903.
Culex kelloggii Theobald, Can. Ent., xxxv, 211, 1903.
Culex peus Speiser, Insektenbörse, xxi, 148, 1904.

A medium sized mosquito, the mesonotum bronzy-brown scaled, frequently ornamented with narrow silvery white lines each side of the posterior portion, running back to the scutellum. The abdomen is blackish or brown, with moderate basal segmental white bands, the one on the basal segment triangular; venter whitish scaled, with angular transverse black bands, which form cusps directed posteriorly. Proboscis dark, with a white ring near the middle. Legs brown, the femora white beneath, the tarsi with white rings at both ends of the joints, small on front and middle legs, distinct on the hind pair; a white line on the outer side of femora and tibiae. Wing-scales wholly dark, fine and hair-like, forming a little tuft at the base of the third vein.

The male genitalia have the second uncal plate large and furnished with denticles. The lobe of the side piece has three rods, a seta, a leaf and a seta.

The larvae are commonly found in grassy ponds or marshes, often in escaped irrigation water. They do not take to artificial receptacles.

This mosquito will enter houses and may become a considerable nuisance in the western part of the country.

Distribution: Mississippi Valley and western prairies to the Pacific Ocean, Mexico to British Columbia.

CANADIAN RECORDS.

Saskatoon, Saskatchewan, August 12, 1918 (H. G. Dyar).
Mission, British Columbia, August, 1919 (E. Hearle).
Wellington, British Columbia, August 8, 1906 (Dyar & Caudell).
Royal Oak, British Columbia, April, 1917 (R. C. Treherne).
Chilliwack, British Columbia, July 3, 1919 (E. Hearle).
Harrison, British Columbia, June 20, 1919 (E. Hearle).

CULEX (CULEX) TERRITANS Walker.

Culex territans Walker, Ins. Saund., Dipt., i, 428, 1856.
Culex restuans Theobald, Mon. Culic., ii, 142, 1901.
Culex brehmei Knab, Proc. Biol. Soc. Wash., xxix, 161, 1916.

A medium sized, reddish brown mosquito, the proboscis and legs all dark, or the tarsi with faint pale brownish rings at the ends of the joints. Mesonotum with narrow curved bronzy brown scales, often ornamented with little patches of light yellowish ones on each side of the middle; but these light spots may be wanting. Abdomen blackish brown above, with moderate basal segmental whitish bands, transverse and even; venter whitish scaled, often with dusky angular transverse bands, the cusps directed anteriorly. Wing-scales fine and hair-like, all brown.

The male genitalia have the second uncal plate short and pointed, without denticles. Lobe of the side piece with three rods, a seta, a leaf and a seta.

The larvae live in dirty ground puddles, and take rather readily to artificial receptacles, such as water-barrels. The adults readily enter houses, thus making this the common house-mosquito of eastern Canada.

Distribution: Eastern North America, Gulf of Mexico to Canada.

CANADIAN RECORDS.

Toronto, Ontario, August 6, 1900 (A. Gibson).
Ottawa, Ontario, August 21, 1900 (J. Fletcher).
White River, Ontario, June 26, 1907 (F. Knab).

CULEX (CULEX) PIPIENS Linnaeus.

Culex pipiens Linnaeus, Syst Nat., ed. x, 602, 1758.
Culex consobrinus R.-Desvoidy, Mem. Soc. d'hist. nat. Paris, iii, 408 1827.
Culex flavipes Macquart, Dipt. Exot., i, part 1, 35, 1838.
Culex haematophagus Ficalbi, Bull. Soc. Ent. Ital., xxviii, 287, 1893.
Culex pallens Coquillett, Proc. U.S. Nat. Mus., xxi, 303, 1898.
Culex varioannulatus Theobald, Mon. Culic., iii, 198, 1903.
Culex azoriensis Theobald, Mon. Culic., iii, 210, 1903.
Culex osakaensis Theobald (♀), Mon. Culic., iv, 439, 1907.
Culex comitatus Dyar & Knab, Proc. Ent. Soc. Wash., xi, 35, 1909.
Culex quasiguiarti Theobald (♀), Mon. Culic., v, 374, 1910.

A medium sized, reddish brown mosquito, the mesonotum with narrow curved reddish brown scales; legs and proboscis blackish scaled, the femora pale below at base. Abdomen blackish above, with moderate basal segmental whitish bands, the band at the base of the second ab-

dominal segment somewhat triangular. Wing-scales narrow and hair-like, wholly dark.

Male genitalia with the second uncal plate narrow and strap-like, the lobe of the side-piece with three rods, two setae, a filament, a leaf and a seta.

The larvae occur in artificial receptacles by preference, but are also found in ground pools when soiled by animal refuse.

This is the common house-mosquito of Europe, introduced by commerce into various temperate regions. It does not persist in the tropics.

Distribution: Europe and Asia, from England to Japan; South America, Argentine and Chile; North America, Virginia to Canada on the Atlantic, and California to British Columbia on the Pacific.

CANADIAN RECORDS.

Jordan, Ontario, July 18, 1919 (W. A. Rose).
Stoney Creek, Ontario, August 17, 1917 (E. Hearle).
Guelph, Ontario, November 29, 1919 (E. Hearle).
Vancouver, British Columbia, September, 1919 (E. Hearle).

CULEX (NEOCULEX) TESTACEUS van der Wulp.*

Culex testaceus van der Wulp, Tidsch. voor Ent., (2), x, 128, 1867.
Culex apicalis Adams, Kans. Univ. Sci. Bull., ii, 26, 1903.
Culex saxatilis Grossbeck, Can. Ent., xxxvii, 360, 1905.
Culex frickii Ludlow, Can. Ent., xxxviii, 132, 1906.

A small blackish mosquito, readily distinguished by the white abdominal bands being apical on the segments instead of basal, though sometimes very narrow. Mesonotum with bronzy brown scales and sometimes a pair of light spots near the middle. Proboscis and legs blackish scaled, the femora whitish beneath. Wing-scales narrow and hair-like, wholly dark.

The male genitalia lack the second uncal plate, the third pair united by a bridge in a characteristic manner. Lobe of the side piece with two capitate rods, three flattened setae and three normal setae.

The larvae occur in grassy marshes, and can be found all summer.

The adults do not bite warm-blooded animals, but have been observed attacking frogs.

Distribution: North America, from Mexico to Canada.

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* This species was for a long time called *Culex territans;* but that name has lately been shown to belong to a preceding species, formerly known as *Culex restuans.*

CANADIAN RECORDS.

Guelph, Ontario, September 17, 1916 (E. Hearle).
Winnipeg Beach, Manitoba, July 1918 (H. G. Dyar).
Wellington, British Columbia, August, 1906 (Dyar & Caudell).
Pitt Mead, British Columbia, June 7, 1919 (E. Hearle).
Royal Oak, British Columbia, April, 1917 (R. C. Treherne).
Agassiz, British Columbia, June 20, 1919 (E. Hearle).
Dewdney, British Columbia, July 4, 1919 (E. Hearle).
Mission, British Columbia, October 9, 1919 (E. Hearle).

CULEX (CLIMACURA) MELANURUS Coquillett.

Culex melanurus Coquillett, Journ. N.Y. Ent. Soc., x, 193, 1902.

A dark brown mosquito, rather over middle size, the abdomen wholly blackish above, without white bands. Proboscis and legs blackish, the femora narrowly whitish beneath. Mesonotum with dark brown scales and conspicuous dark setae. The abdomen has pale triangular basal segmental spots on the sides, the venter pale, with faint darker bands at the apices of the segments. The wing-scales are long, dense, and broader than usual, being ligulate, rather than hair-like, all dark brown.

The male genitalia have the unci membranous and paired, with an outwardly directed basal chitinization. Side piece without lobe, the basal excavation with three stout setae at its tip.

The larvae live in small collections of permanent water in swamps, and are very peculiar in passing the winter as full-grown larvae under the ice. The eggs appear to be laid singly on the surface of water in the summer time. No observations are on record of the biting habits of the adult. The mosquito is rare, and in no way troublesome.

Distribution: Gulf of Mexico and Atlantic watershed to northern New York and New Hampshire, presumably in southern Canada.

CANADIAN RECORDS.

None.

GENUS CULISETA Felt.

The species of *Culiseta* are large mosquitoes, inhabiting temperate latitudes in both Europe and America. The genus contains a small number of species. The larvae inhabit permanent water, the eggs of *Culiseta* proper being deposited in rafts by overwintering females. Some of the species take kindly to artificial containers, but the adults rarely attack man, preferring larger mammals such as horses and cattle.

Two subgenera may be recognized on the characters of the male genitalia, as follows:

1. Unci divided into two outwardly directed plates, Subgenus CULICELLA Felt
   Unci undivided ..... Subgenus CULISETA Felt

This genus has been called THEOBALDIA by English writers; but as there already exists a genus THEOBALDIUS, it seems inadvisable to use the former, differing as it does only by a gender termination. We therefore have recourse to CULISETA, the next name in time of priority.

KEY TO THE CANADIAN SPECIES OF CULISETA.

1. Tarsi with faint whitish rings at both ends of the joints; wings narrow as in *Culex* ..... *dyari* Coquillett
   Tarsal rings if present basal; wings broader 2
2. Tarsi with broad white rings at the bases of some of the joints; wings spotted ..... *alaskaënsis* Ludlow
   Tarsi with very narrow white rings; wings spotted .. *incidens* Thomson
   Tarsi without white rings; wings unspotted 3
3. Wing-scales narrow, hair-like; no scales on the cross-veins, *impatiens* Walker
   Wing-scales broader; scales sometimes present on the cross-veins, *inornatus* Williston

CULISETA (CULICELLA) DYARI Coquillett.

Culex dyari Coquillett, Journ. N.Y. Ent. Soc., x, 192, 1902.
Culex brittoni Felt, Ent. News, xvi, 79, 1905.

A rather large dark brown mosquito. Mesonotum with two bare impressed light brown lines, the vestiture sparse, forming frosted lines, mixed with setae. Abdomen with rather broad whitish bands at the bases of the segments. Legs dark brown, with obscure, narrow pale rings, involving both ends of the tarsal joints; venter pale sordid, with dark bands at the apices of the segments. Proboscis entirely blackish.

The male genitalia have the unci divided into two plates.

The larvae are found in spring in cold bogs, apparently developing from overwintering eggs, but nothing certain is known about the habits of the species. No observations of its biting are on record. The males are attracted rather freely to light.

Distribution: Northern forests, in cold bogs southward to New Jersey.

CANADIAN RECORDS.

White River, Ontario, June 20, 1918 (H. G. Dyar).
Red Deer, Alberta, July 30, 1918 (H. G. Dyar).
Kalso, British Columbia, May 29, 1903 (H. G. Dyar).
Kwinitsa, British Columbia, June 10, 1919 (H. G. Dyar).
Whitehorse, Yukon Territory, July 3, 1919 (H. G. Dyar).

CULISETA (CULISETA) ALASKAËNSIS Ludlow.

Theobaldia alaskaënsis Ludlow, Can. Ent., xxxviii, 326, 1906.

A very large blackish mosquito. Proboscis dark brown, palpi with small white tips at the ends of the joints. Mesonotum uniformly coloured, without impressed lines, the vestiture of black and white narrow curved scales, appearing coarsely frosted. Abdomen black, with basal segmental white bands, the venter mostly whitish scaled. Legs black, mixed with some white scales, femora whitish beneath, femora and tibiae with a white line on the outer side; tarsi with white rings at the bases of the joints, mostly small, but large on the second and third joints of the hind legs. Wings broad, the cross-veins in line; scales black, mixed with some white ones along costa, forming tufts or spots at the bases of first, third and fourth veins and the forks of second, fourth and fifth.

The male genitalia have the unci simple, the penultimate segment without spines.

The larvae live in grassy marshes, generally in river-valleys. The adults pass the winter, hiding in hollow logs and similar locations, and appear very early in the spring. The eggs are deposited in rafts on the surface of the water. The adults will attack man, but are never numerous or particularly troublesome.

Distribution: Rocky Mountains and vicinity to the Yukon Valley, Alaska.

CANADIAN RECORDS.

Calgary, Alberta, April 14, 1913 (N. Criddle).
Edmonton, Alberta, April 27, 1919 (H. G. Dyar).
Banff, Alberta (N. B. Sanson).
Atlin, British Columbia, July 26, 1919 (H. G. Dyar).
Hope, British Columbia, May 20, 1919 (E. Hearle).
Selkirk, Yukon Territory, July 18, 1919 (H. G. Dyar).
Whitehorse, Yukon Territory, June 28, 1919 (H. G. Dyar).
Dawson, Yukon Territory, July 8, 1919 (H. G. Dyar).

CULISETA (CULISETA) INORNATUS Williston.

Culex inornatus Williston, U.S. Dep. Agr., N. Am. Fauna, No. 7, 253, 1893.

Culex magnipennis Felt, Bull. 79, N.Y. State Mus., 278, 1904.

A very large brown mosquito. Proboscis and palpi brown. Mesonotum with two pale brown, slightly impressed lines, the vestiture crossing these, of pale yellowish and dark scales mixed. Abdomen dark brown, with diffused pale yellow basal segmental bands, and scattering scales over the rest; venter sparsely pale yellow scaled. Legs dark brown, with scattering pale scales, the femora and tibiae pale below; tarsi nearly black. Wings broad, the cross-veins somewhat approximated but not very close, long from the breadth of the wing and generally with a few scales; wing-scales linear, all dark, not forming any spots.

The male genitalia have the unci slender and creased; penultimate segment without spines.

The larvae live in permanent ground pools. They do not come in artificial receptacles. The adults hibernate, and the eggs are laid in elongate rafts on the surface of water. The adult is not troublesome, probably attacking by preference the larger mammals.

Distribution: North America, from Mexico to southern Canada, exclusive of the northern forests.

CANADIAN RECORDS.

Aweme, Manitoba, May 17, 1904 (N. Criddle).
Winnipeg Beach, Manitoba, July 9, 1918 (H. G. Dyar).
Regina, Saskatchewan, October 2, 1900 (J. Fletcher).
Saskatoon, Saskatchewan, August 10, 1918 (H. G. Dyar).
Maple Creek, Saskatchewan, October 30, 1903 (T. N. Willing).
Carnduff, Saskatchewan, May 28, 1901 (T. N. Willing).
Olds, Saskatchewan, August 14, 1902 (T. N. Willing).
Kinistino, Saskatchewan, July 10, —— (J. Fletcher).
Shepard, Saskatchewan, July 21, 1901 (T. N. Willing).
Medicine Hat, Alberta, August 23, 1906 (Dyar & Caudell).
Lochearn, Alberta, August 5, 1918 (H. G. Dyar).
Lamoral, Alberta, August 6, 1918 (H. G. Dyar).
Banff, Alberta, August 1, 1918 (H. G. Dyar).
Nicomen, British Columbia, July 27, 1919 (E. Hearle).

CULISETA (CULISETA) INCIDENS Thomson.

Culex incidens Thomson, Kongl. Sven. Freg. Eug. Resa, vi, Dipt., 443 1868.

Culex particeps Adams, Kans. Univ. Bull., ii, 26, 1903.

A large dark mosquito with spotted wings. Mesonotum uniform, without impressed lines; vestiture dark, mixed with yellowish white scales, which form diffuse longitudinal lines, and a spot on each side. Abdomen black, with basal segmental white bands; venter whitish scaled. Legs black, the femora whitish below, the tibiae also more or less whitish within; tarsi with white specks at the bases of the joints, a rather distinct ring at the base of the second hind tarsal. Wings broad, the cross-veins in line, or nealy so; wing-scales black, hair-like, forming more or less conspicuous spots on the bases of the forks of the second and fourth veins, and along the second and fourth veins within the cross-veins.

The male genitalia have the unci simple; a short row of spines on the penultimate segment.

The larvae live in permanent pools of a dirty character, and take readily to artificial receptacles, this being the common water-barrel mosquito of the west. The adults hibernate; the eggs are laid in narrow rafts on the surface of water. The adults will attack man, but rarely, preferring larger mammals. A man on horseback is generally immune, though the horse may be bitten.

Distribution: Northern Rocky Mountains and the Pacific coast from southern California to Alaska.

CANADIAN RECORDS.

Banff, Alberta, July 26, 1918 (H. G. Dyar).
Mission, British Columbia, June 14, 1919 (E. Hearle).
Agassiz, British Columbia, April 22, 1919 (E. Hearle).
Caulfields, British Columbia, May 3, 1919 (E. Hearle).
Hazelton, British Columbia, September 9, 1919 (H. G. Dyar).
Prince Rupert, British Columbia, May 31, 1919 (H. G. Dyar).
Metlakatla, British Columbia, August 1, 1910 (J. H. Keen).
Atlin, British Columbia, July 26, 1919 (H. G. Dyar).
Whitehorse, Yukon Territory, June 26, 1919 (H. G. Dyar).
Dawson, Yukon Territory, July 16, 1919 (H. G. Dyar).

CULISETA (CULISETA) IMPATIENS Walker.

Culex impatiens Walker, List Dipt. Brit. Mus., i, 5, 1848.
Culex pinguis Walker, Lord'd Nat. in Vanc. Id. & B.C., ii, 337, 1866.
Culex absobrinus Felt, Bull. 79, N.Y. State Mus., 391c, 1904.

A very large dark brown mosquito. Proboscis and palpi black. Mesonotum with two broad impressed lighter brown lines, the vestiture sparse, and forming frosted yellowish lines on each side posteriorly.

Abdomen black, with basal segmental white bands; venter mostly whitish. Legs black, the femora white beneath; knee-spots pale. Wings broad, the cross-veins nearly in line, the scales all blackish, coarsely linear; a small tuft at base of third vein, but no scales on the cross-veins.

The male genitalia have the unci simple; a long row of spines on the penultimate segment.

The larvae live in dark permanent pools in the forest, where they are frequently much preyed upon by *Eucorethra underwoodi* larvae. The adults hibernate; the eggs are deposited in broad roundedly triangular rafts on the surface of the water.

Distribution: Northern forests from the Atlantic to Pacific, mountains of California to Alaska.

CANADIAN RECORDS.

Martin's Fall, Ontario (Walker).
White River, Ontario, June, 1918 (H. G. Dyar).
Red Deer, Alberta, August 1, 1918 (H. G. Dyar).
Smith Landing, Alberta, May 30, 1911 (H. V. Radford).
Fort Simpson, Mackenzie, April 21, 1914 (E. A. Preble).
Kalso, British Columbia, July 19, 1903 (H. G. Dyar).
Terrace, British Columbia, August 14, 1919 (H. G. Dyar).
Caulfields, British Columbia, May 3, 1919 (E. Hearle).
Agassiz, British Columbia, June 1, 1917 (A. E. Cameron).
Prince Rupert, British Columbia, May 14, 1919 (H. G. Dyar).
Clayburn, British Columbia, March 25, 1919 (E. Hearle).
Hatzie, British Columbia, April 14, 1919 (E. Hearle).
Hope, British Columbia, May 20, 1919 (E. Hearle).
Whitehorse, Yukon Territory, July 3, 1919 (H. G. Dyar).
Dawson, Yukon Territory, July 15, 1919 (H. G. Dyar).

GENUS MANSONIA Blanchard.

A small genus of general distribution, the species more numerous in the tropics. The larvae are peculiar in having the air-tube adapted for piercing the vascular roots of certain aquatic plants, from which they get their supply of air. The eggs are deposited in rafts in swamps where suitable plants grow, and the young larvae descend to the roots, never coming to the surface again.

The genus has been divided into subgenera on genitalic characters (Dyar, Ins. Ins. Mens., vi, 112, 1918). The single Canadian species belongs to the subgenus COQUILLETTIDIA Dyar.

MANSONIA (COQUILLETTIDIA) PERTURBANS Walker.

Culex perturbans Walker, Ins. Saund., Dipt., 428, 1856.
Culex ochropus Dyar & Knab, Journ. N.Y. Ent. Soc., xv, 100, 1907.

A rather large mosquito with scaly wings and conspicuously ringed legs. Proboscis with many pale scales in the middle, the base and tip dark. Mesonotum with rather coarse pale golden scales, imperfectly covering the surface. Abdomen brown, with a few pale scales at the bases of the segments, and triangular whitish spots at the sides; venter pale scaled, with blackish ones toward the apices of the segments. Legs, dark, with pale scales intermixed, the femora and tibiae pale beneath the hind tibiae with a pale ring at outer third; tarsi with broad white rings at the bases of the joints, the first joint also with a white ring in the middle. Wings with the scales dense and rather broad, brown with white ones intermixed.

The larvae are attached to the roots of a species of *Carex* growing in marshes or the edges of ponds. The winter is passed as half-grown larva. The adults fly several miles from the breeding grounds, and are severe biters. They have been known to descend unused chimneys to get into dwellings which were otherwise screened.

Distribution: North America, Florida to Canada, westward in timbered country to British Columbia.

CANADIAN RECORDS.

Sand Hill, Rideau, Ontario, July 1, 1906 (J. Fletcher).
Kingston, Ontario, June 21, 1917 (A. B. Klugh).
Kenora, Ontario, July 2, 1918 (H. G. Dyar).
Dryden, Ontario, June 30, 1918 (H. G. Dyar).
Jordan, Ontario, July 27, 1916 (E. Hearle).
Aweme, Manitoba, June 30, 1906 (N. Criddle).
Kalso, British Columbia, July 2, 1903 (R. P. Currie).
Vancouver, British Columbia, August 22, 1919 (E. Hearle).
Hatzie, British Columbia, July 22, 1919 (E. Hearle).

GENUS PSOROPHORA Robineau-Desvoidy,

A genus of tropical American origin, developed as an extreme specialization of the *Aëdes* type. A number of species occur in the southern United States, some of them straying into southern Ontario.

The genus contains two subgenera, which divide by genitalic characters as follows:

Clasp filament furcate or angled; harpago with setae evenly over the bulbous tip.....PSOROPHORA Robineau-Desvoidy

Clasp-filament swollen mesially; harpago with all the setae on the inner aspect, in some species soldered to the side-piece,

JANTHINOSOMA Lynch Arribalzaga

One species of PSOROPHORA will probably be found to reach Canada, as it has been reported from the Champlain Valley in northern New York, but a short distance from the Canadian boundary. One species of JANTHINOSOMA, also, is known to occur.

PSOROPHORA (PSOROPHORA) CILIATA Fabricius.

Culex ciliata Fabricius, Ent. Syst., iv, 401, 1794.
Culex molestus Wiedemann, Dipt. Exot., 7, 1821.
Culex tibialis Robineau-Desvoidy, Mem. Soc. Nat. Hist. Paris, iii, 404, 1827.
Culex rubidus Robineau-Desvoidy, Mem. Soc. Nat. Hist. Paris, iii, 404, 1827.
Psorophora boscii Robineau-Desvoidy, Mem. Soc. Nat. Hist. Paris, iii, 413, 1827.
Culex conterrens Walker, Ins. Saund., Dipt., 427, 1856.
Culex perterrens Walker, Ins. Saund., Dipt., 431, 1856.

A very large mosquito, with dusky wings and shaggy, white-ringed legs. Scales on palpi and base of proboscis mostly shaggy and erect, dark. Mesonotum with smooth nude areas, a line of golden scales in the middle, and large patch of silvery gray ones on the shoulders. Abdomen brown scaled, with scattering white ones, especially toward the tips of the segments. Legs with the yellow integument showing in many places; black erect scales at ends of femora, all of tibiae and apices of tarsal joints, the tarsi, especially the hind pair, broadly white-ringed at the bases. Wings with narrow brown scales, mixed with some whitish ones along the costa.

The larvae live in temporary rain-puddles, and are predaceous upon the larvae of other mosquitoes with the same habit, either *Psorophora* (subgenus *Janthinosoma*) or *Aëdes*. The period of larval life is very short. The winter is passed in the egg state, the eggs being spinose and adapted to withstand dessication. The adult is a severe biter; but may be classed otherwise as a beneficial insect, since its larva destroys many other mosquito larvae.

Distribution: Brazil to the eastern United States east of the plains to northern New York.

CANADIAN RECORDS.

None.

PSOROPHORA (JANTHINOSOMA) SAYI Dyar & Knab.

Culex musicus Say (not Leach), Journ. Acad. Nat. Sci. Phil., vi, 149, 1827.
Culex posticatus Coquillett (not Wiedemann), U.S. Dept. Agr., Div. Ent., Circl. 40, 2 Ser., 6, 1900.
Janthinosoma discrucians Giles (not Walker), Gnats or Mosq., 2 ed. 339 1902.
Ianthosoma mexicanum Blanchard (not Bellardi), Les Moust., 234, 1905.
Janthinosoma sayi Dyar & Knab, Journ. N.Y. Ent. Soc., xiv, 181, 1906.
Janthinosoma sayi Theobald, Mon. Culic., iv, 155, 1907.

A large brown mosquito, the hind legs shortly shaggy and tipped with white. Palpi, legs and abdomen black with blue reflection. Head with dense erect golden scales; mesonotum with sparse golden scales; abdomen blue-black dorsally, with lateral triangular apical segmental yellow patches, confluent with the golden yellow venter; legs blue-black, the vestiture of the hind pair shortly erect, tip of third tarsal and all of the fourth and fifth white. Wings slightly smoky, the scales narrow, all dark.

The larvae live in temporary rain-puddles, and develop rapidly. The period of larval life is very short. The winter is passed in the egg state, the eggs being spinose and adapted to withstand dessication. The adult is generally rare, but conspicuous when seen. It will bite in day time in the open, but is never numerous enough to be troublesome.

Distribution: Atlantic and Gulf States to southern Ontario, Cuba and Bahamas.

CANADIAN RECORDS.

Jordan, Ontario, August 3, 1916 (E. Hearle).

GENUS AËDES Meigen.

A large genus of world-wide distribution. Species of this genus are especially abundant in northern and arctic regions. The winter is passed in the egg state, and development takes place in ground pools filled by snow-water. The adults are all severe biters, and often occur in enormous numbers. They are killed by the first hard frosts.

The genus has been divided into a number of subgenera on the characters of the male genitalia. The groups occurring in Canada may be separated as follows:

1. Harpagones present, strap-shaped organs with terminal filament 2
   Harpagones absent 3

2. Side piece with basal and apical lobes,
HETERONYCHA Lynch Arribalzaga
Side piece with basal lobes only,
TAENIORHYNCHUS Lynch Arribalzaga
Side piece without lobes.....FINLAYA Theobald
3. Side piece with apical appendage.....ECCULEX Felt
Appendage of side piece subapical, modified.....AËDES Meigen

KEY TO THE CANADIAN SPECIES OF AËDES.

1. Tarsi with white rings on both ends of the joints.....2
Tarsi with white rings basally on the joints 6
Tarsi without white rings.....9
2. Wing-scales markedly bicoloured.....3
Wing-scales uniformly dark, or nearly so.....4
3. Larger species; wing-veins evenly mottled
campestris Dyar & Knab
Smaller species; third vein darker scaled than the adjoining ones,
curriei Coquillett
4. Mesonotum pale, with broad dark median stripe,
atropalpus Coquillett
Mesonotum differently coloured.....5
5. Mesonotum pale yellowish with dark spots..*varipalpus* Coquillett
Mesonotum uniformly brown, or nearly so....*canadensis* Theobald
6. Proboscis of the female white-ringed.....*sollicitans* Walker,
nigromaculis Ludlow
Proboscis of the female without white ring.....7
7. White rings of tarsi broad; mesonotum varied with whitish.....8
Tarsal rings narrow; mesonotum uniformly brown,
cantator Coquillett, *vexans* Meigen
8. Yellowish species, the pale abdominal scales yellow, diffused,
fletcheri Coquillett, *riparius* Dyar & Knab
Not yellowish, the pale abdominal scales white, generally concrete,
excrucians Walker, *stimulans* Walker, *fitchii* Felt & Young
9. Mesonotum dark centrally, silvery gray at the sides..*triseriatus* Say
Mesonotum yellow or brown, with or without dark bands.....10
10. Abdomen with continuous, or nearly so, white lateral line,
cinereus Meigen
Abdomen transversely banded, the lateral spots never joined....11
11. Wing scales markedly bicoloured on alternating veins.....12
Wing scales uniformly dark coloured, or nearly so.....13
12. Abdomen with median dorsal longitudinal pale stripe,
spencerii Theobald

Abdomen generally without the median stripe, *idahoensis* Theobald

13. Mesonotum typically with central broad undivided dark band.... 14
Mesonotum with central dark band, if present, distinctly divided.. 15

14. Mesonotum creamy yellow at the sides.....*hirsuteron* Theobald
Mesonotum golden or reddish brown at the sides; median stripe sometimes divided, or mesonotum uniformly dark brown, *punctor* Kirby
Mesonotum contrastingly yellow at the sides...*aurifer* Coquillett

15. Mesonotum with paired brown lines..... 16
Mesonotum uniformly dark brown, without lines..... 17

16. Mesonotum yellowish, lines narrow, well separated; a very small species.....*aldrichi* Dyar & Knab
Mesonotum yellow (or gray), sometimes more or less suffused with brown centrally, the margin remaining yellow; lines narrow, sometimes obsolete; medium sized species..*lazarensis* Felt & Young
Mesonotum yellow (rarely gray), the dark lines broad, heavy, well contrasted and passing back around the ante-scutellar space; a larger species.....*pionips* Dyar
Mesonotum yellow, lines slender, often conjointed into a median stripe; legs very deep black.....*diantaeus* Howard, Dyar & Knab
Mesonotum yellow, the side stripes darker and heavier than the median pair; small species, confined to Pacific coast region, *cyclocerculus* Dyar
Mesonotum yellow; lines moderate, normal; medium sized species, confined to Pacific coast region.....*leuconotips* Dyar
Mesonotum yellow to brown; lines distinct, broad; a large species, confined to Pacific coast region.....*aboriginis* Dyar
Mesonotum gray, with central brown shade, lines fine, dark; a small species.....*impiger* Walker
Mesonotum mossy yellow; lines narrow and very approximate, *pullatus* Coquillett

17. Thorax with long hairs, especially below.....*nearcticus* Dyar
Thorax with normal setae..... 18

18. Mesonotum light gray, with traces of dark lines, or a central brown shade, sometimes covering the whole mesonotum; a small species, *prodotes* Dyar
Mesonotum dark gray, often with whitish shades at each side; a large species.....*trichurus* Dyar,
Mesonotum uniformly dark brown; a medium sized species, very fond of entering houses.....*intrudens* Dyar

As indicated above, the variation in colour of the mesonotum is considerable in the same species, so that the characters overlap on all sides. The male genitalia are of great assistance to determination in such cases,

especially in the subgenus HETERONYCHA, where the confusion due to this variability is likely to be greatest.

KEY TO THE CANADIAN SPECIES OF HETERONYCHA BY THE MALE GENITALIA.

1. Basal lobes modified, obsolete as such, but leaving a large spine on one side and two approximate setae on the other, the latter sometimes obsolete.....(group *pullatus*) 2
   Basal lobes more or less developed, with or without an accompanying spine.....4
2. Basal lobe large, with two stout spines.....3
   Basal lobe small, with two stout spines.....*pullatus* Coquillett
   Basal lobe absent, no basal spines.....*aurifer* Coquillett
3. A slight hairy area distal of apical lobe.....*intrudens* Dyar
   A strong hairy area proximal of apical lobe,
   diantaeus Howard, Dyar & Knab
4. Basal lobe more or less expanded and tubercular, short-haired, with or without accompanying spine.....5
   Basal lobe unmodified, uniformly long-haired.....19
5. Apical lobe very large, resembling the basal one, with many straight stout, lanceolately thickened, rather long setae (group *canadensis*)
   canadensis Theobald
   Apical lobe with short, recurved flattened, clinging setae.....6
   Apical lobe with normally shaped setae.....9
6. Spine of basal lobe very thick, angularly curved and of a pale appearance.....(group *hirsuteron*)..7
   This structure a normal curved spine, not differentiated in texture from other setae, although larger.....(group *punctor*)..8
7. The four species *spencerii* Theobald, *idahoensis* Theobald, *hirsuteron* Theobald, and *aldrichi* Dyar & Knab have no marked differences in the male genitalia.
8. The four species *punctor* Kirby, *cyclocerculus* Dyar, *leuconotips* Dyar and *aboriginis* Dyar have no marked differences in the male genitalia. The second and third species have a stronger spine on the basal lobe than the first and fourth; but the character is relative.
9. Setae on the apical lobe coarse and somewhat thickened,
   (group *curriei*)..10
   These setae normal, fine and slender.....11
10. Basal lobe with two stout spines on the margin....*curriei* Coquillett
    Basal lobe with coarse setae on the margin, no spines,
    campestris Dyar & Knab

11. Setae on apical lobe inwardly directed, on inner surface of lobe (group *stimulans*) 12
Setae on apical lobe outwardly directed, on outer surface of lobe (group *impiger*) 16
12. Basal lobe of side piece with a stout spine 13
Basal lobe without a spine ..... *excrucians* Walker
13. Spine on basal lobe very strong and distinct 14
This spine scarcely differentiated from adjacent setae 15
14. Basal lobe large, rugose-tubercular; filament of harpago angularly widened beyond middle ..... *stimulans* Walker
Basal lobe very small with few setae, non-rugose; filament of harpago smoothly widened at middle ..... *cantator* Coquillett
Basal lobe rugose-papillose, the area extending nearly to apical lobe; filament of harpago broadly expanded near base,
fletcheri Coquillett
15. Spine fairly strong; filament of harpago short, notched at base,
fitchii Felt & Young
Spine weaker; filament of harpago long, with broad knife-blade expansion ..... *riparius* Dyar & Knab
16. Setae on apical lobe moderate and numerous 17
Setae on apical lobe small, very few 18
17. Setae on basal lobe many, much shorter than the spine,
lazarensis Felt & Young
These setae sparse, not much shorter than the spine. . *pionips* Dyar
18. Adjacent setae of basal lobe about as long as the spine, *prodotes* Dyar
These setae distinctly shorter than the spine ..... *impiger* Walker
19. Harpago rather long; filament sickle-shaped with double dorsal membranous ridge (group *neracticus*) ..... *nearcticus* Dyar
Harpago long, the filament bud-shaped (group *trichurus*),
trichurus Dyar

SUBGENUS HETERONYCH Lynch Arribalzaga.

Group PULLATUS.

AËDES (HETERONYCHA) AURIFER COQUILLETT.

Culex aurifer Coquillett, Can. Ent., xxxv, 255, 1903.

A medium sized to rather large brown-black mosquito. Head golden-scaled in the middle and sides, dark brown between. Mesonotum with a very broad median deep blackish brown stripe, leaving the sides narrowly golden yellow. Abdomen black dorsally, with elongate triangular white basal segmental lateral spots; venter mostly whitish. Legs deep black, the femora broadly white below except at tips. Wing scales narrow, black.

The larvae live in early spring pools, particularly cranberry bogs, hatching from overwintering eggs. The attack of the adult is described as blood-thirsty. The mating habits of the males are unknown. The species is local and rare.

Distribution: Southern Canada to New Jersey; Minnesota.

CANADIAN RECORDS.

Ottawa, Ontario, June 12, 1917 (A. B. Klugh).

AËDES (HETERONYCHA) PULLATUS Coquillett.

Culex pullatus Coquillett, Proc. Ent. Soc. Wash., vi, 168, 1904.
Aëdes acrophilus Dyar, Ins. Ins. Mens., v, 127, 1917.

A medium sized black mosquito. Mesonotum dull olivaceous yellow when fresh, fading to mossy whitish; lines distinct, narrow, approximate, median lines normally present, the side stripes more often obsolete. Abdomen black, the basal segmental white bands narrowed centrally or obsolete dorsally, widened at the sides; venter pale, with dark apical segmental bands. Legs black, the femora pale below; knee-spots white. Wing-scales narrow, all dark.

The winter is passed in the egg stage. The larvae develop in early ground-pools, more especially muddy pools along streams and lakes. They are somewhat late in development, being the last of the forest species to be found as larvae. The species frequents high altitudes. The males swarm after sunset in openings of the forest or over willows. In the far north, in June, when it is light practically all night, the swarms may be seen as early as 4 p.m. when the sun passes behind a temporary cloud.

Distribution: Alaska and the Yukon, down the Rocky mountains to Colorado.

CANADIAN RECORDS.

Lake Louise, Alberta, July 11, 1918 (H. G. Dyar).
Banff, Alberta, July 14, 1918 (H. G. Dyar).
Kalso, British Columbia, July 2, 1903 (H. G. Dyar).
Kwinitsa, British Columbia, May 29, 1919 (H. G. Dyar).
Bennett, British Columbia, July 28, 1919 (H. G. Dyar).
Atlin, British Columbia, July 23, 1919 (H. G. Dyar).
Carcross, Yukon Territory, July 21, 1919 (H. G. Dyar).
Whitehorse, Yukon Territory, June 27, 1919 (H. G. Dyar).
Tahkeena River, Yukon Territory, July 19, 1919 (H. G. Dyar).

Hootalinqua, Yukon Territory, July 15, 1919 (H. G. Dyar).
Tantalus Mine, Yukon Territory, July 6, 1919 (H. G. Dyar).
Big Salmon, Yukon Territory, July 15, 1919 (H. G. Dyar).
Carmack's, Yukon Territory, July 14, 1919 (H. G. Dyar).
Dawson, Yukon Territory, July 7, 1919 (H. G. Dyar).

AËDES (HETERONYCHA) INTRUDENS Dyar.

Aëdes intrudens Dyar, Ins. Ins. Mens., vii, 23, 1919.

A medium sized, black mosquito, very fond of entering houses. Head with brown scales on the vertex, a narrow line of black ones on each side, and a patch of creamy ones below. Mesonotum with dark bronzy brown scales, the posterior lateral stripes often showing faintly blackish, with a slender light line within. Abdomen black, with basal segmental white bands, generally not contracted in the middle; venter whitish scaled. Legs black, the femora pale beneath. Wing-scales dark.

Liable to be confused with the *abserratus* form of *punctor* or the heavily suffused form of *prodotes*, the male genitalia abundantly diagnostic in both cases. Also similar to the unlined form of *lazarensis*; but that has always a pale margin to the mesonotum, lacking in *intrudens*.

The winter is passed in the egg state. The larvae develop in early ground-pools in spring, this being one of the especially early species. The adults are short-lived, disappearing comparatively early in the season. This is the most troublesome of the forest mosquitoes, from its habit of entering houses. When large numbers get in, as often happens, sleep is difficult. No other forest species behaves in this manner.

The mating habits of the males have not been observed.

Distribution: Northern forests, Atlantic to Pacific.

CANADIAN RECORDS.

Chats Rapids, Quebec, May 24, 1900 (J. Fletcher).
White River, Ontario, June 24, 1907 (F. Knab).
Nipigon, Ontario, June 26, 1918 (H. G. Dyar).
Dryden, Ontario, June 29, 1918 (H. G. Dyar).
Winnipeg Beach, Manitoba, July 5, 1918 (H. G. Dyar).
Lake Minnewanka, Alberta, July 22, 1918 (H. G. Dyar).
Banff, Alberta, July 7, 1918 (H. G. Dyar).
Laggan, Alberta, July 11, 1918 (H. G. Dyar).
Terrace, British Columbia, August 12, 1919 (H. G. Dyar).
Salvus, British Columbia, June 3, 1919 (H. G. Dyar).
Kwinitsa, British Columbia, May 22, August 14, 1919 (H. G. Dyar).

AËDES (HETERONYCHA) DIANTAEUS Howard, Dyar & Knab.

Aëdes diantaeus Howard, Dyar & Knab, Mosq. No. & Cent. Am. & W. I., iv. 758, 1917.

A medium sized black mosquito. Mesonotum yellow, the two median blackish lines distinct, narrow, sometimes joined into a single median stripe; side stripes generally weak. Abdomen black, the white bands obsolete dorsally, forming triangular spots at the sides at the bases of the segments; venter whitish, the segments black at their apices. Legs deep black, the femora white below, broadly so at base. Wing-scales narrow, all dark.

Liable to be confused with the normal form of *lazarensis*, from which there is no marked distinction. The form of *diantaeus* with single dark stripe closely resembles the normal form of *punctor*; but is more slender, the legs blacker. Male genitalia always diagnostic.

The winter is passed in the egg state. Larvae in early ground-pools especially cold pools in spruce bogs; but in one river valley breeding in flood-pools in summer.

The males do not swarm, but attack the females singly as these are tempting to bite some warm-blooded animal.

Distribution: Northern forests from Atlantic to Pacific.

CANADIAN RECORDS.

White River, Ontario, June 17, 1918 (H. G. Dyar).
Terrace, British Columbia, August 13, 1919 (H. G. Dyar).
Salvus, British Columbia, June 9, 1919 (H. G. Dyar).

Group HIRSUTERON.

AËDES (HETERONYCHA) SPENCERII Theobald.

Culex spencerii Theobald, Mon. Culic., ii, 99, 1901.

A rather small, dark gray mosquito, inhabiting the open prairie. Mesonotum dark brown in the middle, a grayish stripe on each side on the margin and over antescutellar space. Abdomen with diffuse grayish white bands at bases and apices of segments, and a line of the same colour down the middle, cutting the black ground into paired squarish spots; venter whitish. Legs black and grayish white, the latter colour predominating beneath; femora white below. Wings with the costa, first, third and fifth veins black-scaled, the alternating ones white-scaled.

The winter is passed in the egg stage, the larvae developing in early spring pools. The adults inhabit the open prairie, avoiding timber. The males swarm after sunset over prominent objects on the prairie.

Distribution: Prairies of central Canada and northern edge of the United States.

CANADIAN RECORDS.

Aweme, Manitoba, July 28, 1916 (N. Criddle).
Winnipeg, Manitoba, June 22, 1907 (F. Knab).
Oxbow, Saskatchewan, May 30, 1907 (F. Knab).
Belonge Creek, Saskatchewan, July, 1907 (V. A. Armstrong).
Kinisteno, Saskatchewan, July 10, —— (J. Fletcher).
Regina, Saskatchewan, June 9, 1907 (T. N. Willing).
Strassburg, Saskatchewan, June 3, 1907 (T. N. Willing).
Carnduff, Saskatchewan, May 28, 1901 (J. Fletcher).
Alameda, Saskatchewan, June 5, 1902 (J. Fletcher).
Olds, Saskatchewan, July 5, 1901 (J. Fletcher).
Rosthern, Saskatchewan, July 13, —— (J. Fletcher).
Saskatoon, Saskatchewan, August 11, 1918 (H. G. Dyar).
Lochearn, Alberta, August 5, 1918 (H. G. Dyar).
Lamoral, Alberta, August 6, 1918 (H. G. Dyar).
Nordegg, Alberta, August 6, 1918 (H. G. Dyar).
Banff, Alberta, July 8, 1918 (H. G. Dyar).
Kalso, British Columbia, June 13, 1903 (R. P. Currie).

AËDES (HETERONYCHA) IDAHOENSIS Theobald.

Grabhamia spencerii idahoensis Theobald, Mon. Culic., iii, 250, 1903.

A rather small, dark gray mosquito, inhabiting open, dry country. Mesonotum dark brown in the middle, a grayish stripe on each side on the margin and over antescutellar space. Abdomen with grayish white bands at the bases of the segments, narrowed centrally, and a few white scales at the apices of the segments also; venter whitish. Legs black and grayish white, the latter colour predominating beneath; femora white below. Wings with the costa, first, third and fifth veins black-scaled, the alternating ones white-scaled.

In some specimens there is a more or less complete band of pale scales down the middle of the abdomen, and these are indistinguishable from *spencerii*.

The winter is passed in the egg state, the larvae developing in early spring pools. The adults inhabit open country, avoiding timber. The males swarm after sunset over prominent objects. There are larval differences between *idahoënsis* and *spencerii*, and they do not occupy the same territory; but the adults, under exceptional circumstances, may be confused.

Distribution: Dry valleys from Colorado and Montana to Nevada and Washington, probably in Canada, at least in the Okanagan Valley of British Columbia.

CANADIAN RECORDS.

None.

AËDES (HETERONYCHA) HIRSUTERON Theobald.

Culex hirsuteron Theobald, Mon. Culic., ii, 98, 1901.
Culex pretans Grossbeak, Ent. News, xv, 332, 1904.
Culex aestivalis Dyar, Journ, N.Y. Ent. Soc., xii, 245, 1904.
Aëdes vinnipegensis Dyar, Ins. Ins. Mens., vii, 34, 1919.

A rather small, dark gray mosquito. Mesonotum dark brown in the middle, gray on the sides and over antescutellar space. Abdomen black, with basal segmental straight white bands; venter whitish. Wing scales all dark, but the costa, first and third veins distinctly darker than the others. Legs black, whitish below, the femora largely white; knee-spots white.

The winter is passed in the egg state, the larvae developing in early spring pools. The mating habits of the males are unobserved. The form *vinnipegensis* is a diminutive race from Manitoba; *aestivalis* is the western form, large and showing slight larval differences. The adults inhabit wooded country, not being found in the open.

Distribution: Eastern United States from the Gulf of Mexico to southern Canada, thence along the southern fringe of the forest to the Pacific coast.

CANADIAN RECORD.

Ottawa, Ontario, June 16, 1917 (A. B. Klugh).
Winnipeg Beach, Manitoba, July 4, 1918 (H. G. Dyar).
Aweme, Manitoba, July 6, 1910 (N. Criddle).
Kaslo, British Columbia, July 4, 1903 (H. G. Dyar).
Lardo, British Columbia, July 7, 1093 (H. G. Dyar).
Sicamous, British Columbia, July 28, 1916 (C. G. Hewitt).
Ainsworth, British Columbia, July 10, 1903 (H. G. Dyar).
Wigwam, British Columbia, August 14, 1903 (H. G. Dyar).
Prince George, British Columbia, September 7, 1919 (H. G. Dyar).
Nanoose Bay, British Columbia, August 1, 1903 (J. Fletcher).

AËDES (HETERONYCHA) ALDRICHI Dyar & Knab.

Aëdes aldrichi Dyar & Knab, Proc. U.S. Nat. Mus., xxxv, 57, 1908.

A small dark gray mosquito. Mesonotum yellowish, with two median dark brown lines and short posterior lateral ones. Abdomen black, with basal segmental white bands, often narrowed in the middle; venter whitish. Legs black, largely whitish below, the femora white below. Wing scales all blackish.

The larvae occur in flood pools shaded by bushes. The adults are often extremely small, so as to pass through window-screens. They inhabit the woods in river-bottoms, not coming out into open country. The adults are voracious biters.

Distribution: River valleys of the Rocky Mountain watershed, both east and west.

Canadian Records.

Mission, British Columbia, August 4, 1919 (E. Hearle).
Nicomen Island, British Columbia, June 15 to August 3, 1919 (E. Hearle).
Chilliwack, British Columbia, July 2, 1919 (E. Hearle).
Agassiz, British Columbia, July 16, 1919 (E. Hearle).
Ruskin, British Columbia, July 23, 1919 (E. Hearle).
Hope, British Columbia, August 3, 1919 (E. Hearle).
Abbotsford, British Columbia, July 12, 1920 (H. G. Dyar).

Group Punctor.

Aëdes (Heteronycha) punctor Kirby.

Culex punctor Kirby, Richardson's Fauna Bor.-Am., iv, 309, 1837.
Culex implacabilis Walker, List Dipt. Brit. Mus., i, 7, 1848.
Culex provocans Walker, List Dipt. Brit. Mus., i, 7, 1848.
Culex abserratus Felt & Young, Science, n.s., xx, 312, 1904.
Culicelsa auroides Felt, Bull. 79, N.Y. State Mus., 448, 1905.
Aëdes centrotus Howard, Dyar & Knab, Mosq. No. & Cent. Am. & W. I., iv, 747, 1917.

A rather large blackish mosquito. Mesonotum with dark yellow or gray scales on the sides, a quadrate broad dark brown band in the middle. Abdomen black, with basal segmental white bands, usually narrow and narrowed centrally; venter white-scaled. Legs black, the femora white below. Wing-scales wholly dark.

In the east, the mesonotum is commonly suffused with brown, with the dark central band still visible (form *centrotus*), or entirely dark brown (form *abserratus*). The latter is difficult to distinguish from *intrudens*. In the west, the typical form (*punctor* = *auroides*) predominates, suffused examples being rare. Here the sides of the mesonotum are as often gray as yellow; in the east, always yellow. Another variation which occurs throughout the range, although not abundantly, has the median mesonotal stripe divided, forming two lines. This is very difficult to distinguish from *lazarensis*. Both the forms of *diantaeus*, also, closely resemble corresponding forms of *punctor*. This is, however, generally a larger and more robust mosquito than *diantaeus*, the legs less deep black.

The winter is passed in the eggs state, the larvae developing in early spring pools, particularly in spruce swamps. None were found in the flood-pools referred to as breeding places for *diantaeus* and others. The adults are severe biters, and can be found till frost in the northern woods, although there is but a single annual generation.

Distribution: Canadian forests from Atlantic to Pacific except the rainy Pacific belt; mountains of New England, New York and Minnesota.

CANADIAN RECORDS.

Rigolet, Labrador, July 18, 1906 (C. W. Johnson).
St. Lewis Inlet, Labrador, July 12, 1906 (C. W. Johnson).
Cape Charles, Labrador, July 28, 1906 (C. W. Johnson).
Younghall, New Brunswick, July 2, 1908 (A. Gibson).
Martin Fall, Ontario (Kirby).
Fort Hope, Ontario, June 27, 1918 (H. N. Awrey).
Moose Factory, Ontario, July 26, 1918 (H. N. Awrey).
Mammamattawa, Ontario, August 27, 1903 (W. J. Wilson).
White River, Ontario, June 24, 1907 (F. Knab).
Height of Land, Ontario, June 7, 1918 (H. N. Awrey).
Osnaburg, Ontario, June 21, 1918 (H. N. Awrey).
Ghost River, Ontario, July 7, 1918 (H. N. Awrey).
Albany, Ontario, July 10, 1918 (H. N. Awrey).
Attawapiscat, Ontario, July 13, 1918 (H. N. Awrey).
Kenogami River, Ontario, June 30, 1903 (W. J. Wilson).
Nipigon, Ontario, June 26, 1918 (H. G. Dyar).
Dryden, Ontario, June 27, 1918 (H. G. Dyar).
Kenora, Ontario, July 2, 1918 (H. G. Dyar).
Winnipeg Beach, Manitoba, July 4, 1918 (H. G. Dyar).
Prince Albert, Saskatchewan, August 14, 1918 (H. G. Dyar).
Saskatoon, Saskatchewan, August 10, 1918 (H. G. Dyar).
Red Deer, Alberta, July 29, 1918 (H. G. Dyar).
Lochearn, Alberta, August 5, 1918 (H. G. Dyar).
Lake Minnewanka, Alberta, July 22, 1918 (H. G. Dyar).
Edmonton, Alberta, May 4, 1919 (H. G. Dyar).
Banff, Alberta, July 9, 1918 (H. G. Dyar).
Field, British Columbia, August 15, 1903 (H. G. Dyar).
Agassiz, British Columbia, May 1, 1919 (E. Hearle).
Prince George, British Columbia, May 12, 1919 (H. G. Dyar).
Hazelton, British Columbia, September 6, 1919 (H. G. Dyar).
Terrace, British Columbia, August 12, 1919 (H. G. Dyar).
Kwinitsa, British Columbia, May 22, 1919 (H. G. Dyar).
Atlin, British Columbia, July 22, 1919 (H. G. Dyar).

Carcross, Yukon Territory, July 21, 1919 (H. G. Dyar).
Whitehorse, Yukon Territory, June 26, 1919 (H. G. Dyar).
Tahkeena River, Yukon Territory, July 19, 1919 (H. G. Dyar).
Byer's Camp, Yukon Territory, July 6, 1919 (H. G. Dyar).
Carmack's, Yukon Territory, July 14, 1919 (H. G. Dyar).
Selkirk, Yukon Territory, July 13, 1919 (H. G. Dyar).
Horse Falls, Yukon Territory, July 13, 1919 (H. G. Dyar).
Dawson, Yukon Territory, July 7, 1919 (H. G. Dyar).

AËDES (HETERONYCHA) LEUCONOTIPS Dyar.

Aëdes leuconotips Dyar, Ins. Ins. Mens., viii, 24, 1920.

A rather large blackish mosquito. Mesonotum brownish yellow, with two median dark brown lines, and short posterior lateral ones of the same colour. Abdomen black, with basal segmental white bands, narrow and narrowed centrally; venter white-scaled, with some black ones at the tips of the segments. Legs black, the femora white below; knee-spots narrowly white. Wing-scales all dark.

The markings are not distinguishable from *lazarensis*, although, as seen from the male genitalia and larvae, the species is extremely close to *punctor*. The winter is passed in the egg state, the larvae developing in early muskeg-pools in the rainy Pacific coast strip. The mating habits of the males have not been observed.

Distribution: Pacific coast, British Columbia to Alaska.

CANADIAN RECORDS.

Prince Rupert, British Columbia, May 22, 1919 (H. G. Dyar).

AËDES (HETERONYCHA) CYCLOCERCULUS Dyar.

Aëdes cyclocerculus Dyar, Ins. Ins. Mens., viii, 23, 1920.

A medium sized blackish mosquito. Mesonotum brownish yellow, with two median brown lines, and short thick posterior lateral ones, heavier and blacker than the median ones. Abdomen black, with narrow basal segmental white bands, narrowed centrally; venter whitish-scaled. Legs black, mixed with gray scales, especially below, the femora white below. Wing-scales wholly dark.

By the male genitalia and larvae, this species is closely allied to *punctor*. It is a rather small species, the winter being passed in the egg state, the larvae developing in early muskeg-pools in the rainy Pacific coast strip. The mating habits of the males have not been observed.

Distribution: Pacific coast, British Columbia to Alaska.

CANADIAN RECORDS.

Prince Rupert, British Columbia, May 11, 1919 (H. G. Dyar).

AËDES (HETERONYCHA) ABORIGINIS Dyar.

Aëdes aboriginis Dyar, Ins. Ins. Mens., v, 99, 1917.

A large blackish mosquito. Mesonotum yellow-brown, with two broad central stripes, sometimes confluent, and short thick posterior lateral ones. Abdomen black, with basal segmental narrow white bands; venter white-scaled, with more or less distinct black bands at the apices of the segments. Legs black, some whitish scales intermixed; femora white below. Wing-scales wholly dark.

The markings of the mesonotum are not separable from *lazarensis*. The form with the mesonotal stripes united is practically as in *punctor*, to which this species is closely allied in the male genitalia; the larvae however, are distinctive. The winter is passed in the egg state, the larvae developing in early spring pools of foul character, not in typical muskeg-pools. The males have been observed swarming as late as 9 a.m. in bright sunlight, although in deep forest and shaded by the trunks of large trees. This habit is different to that of any other known *Aëdes*. The females bite by day or night, as with any other forest mosquito.

Distribution: Pacific coast, from Washington to Alaska.

CANADIAN RECORDS.

Royal Oak, British Columbia, May 4, 1917 (R. C. Trehearne).
West Holme, British Columbia, May 3, 1917 (A. E. Cameron).
Prince Rupert, British Columbia, May 11, 1919 (H. G. Dyar).

GROUP IMPIGER.

AËDES (HETERONYCHA) LAZARENSIS Felt & Young.

Culex lazarensis Felt & Young, Science, n.s., xx, 312, 1904.
Culex borealis Ludlow, Can. Ent., xliii, 178, 1911.

A rather large blackish mosquito. Mesonotum dull yellow, often a little mixed with blackish; two median black-brown lines and short posterior lateral ones, usually both broad and distinct. Abdomen black, with basal segmental white bands, often narrowed in the middle; venter whitish-scaled, with more or less black at the apices of the segments. Legs black, femora white below; knee-spots white narrowly. Wing scales all black.

The colouration of the mesonotum varies from the normal yellow to gray in the Yukon valley (form *borealis*), and in another variety is more or less overspread with brown. The lines may be narrow, or obsolete, or

much extended, in the extreme form rendering the whole mesonotum black.

No colouration characters can be given to separate all forms of *lazarensis* from *punctor*, *diantaeus*, *aboriginis*, *intrudens*, etc.

The winter is passed in the egg state, the larvae developing in early ground pools in forest, and at least in one case in flood pools. The males swarm after sunset at projecting branches of spruce trees and similar locations. The females are good biters, flying in most profusion shortly after dark.

Distribution: Northern forests, from Atlantic to Pacific, except the moist Pacific coast belt.

CANADIAN RECORDS.

Ottawa, Ontario, —·—, —·— (J. Fletcher).
Height of Land, Ontario, June 17, 1918 (H. N. Awrey).
Osnaburg, Ontario, June 21, 1918 (H. N. Awrey).
Fort Hope, Ontario, June 27, 1918 (H. N. Awrey).
White River, Ontario, June 25, 1907 (F. Knab).
Nipigon, Ontario, June 26, 1918 (H. G. Dyar).
Dryden, Ontario, July 1, 1918 (H. G. Dyar).
Kenora, Ontario, July 2, 1918 (H. G. Dyar).
Red Deer, Alberta, July 30, 1918 (H. G. Dyar).
Lochearn, Alberta, August 5, 1918 (H. G. Dyar).
Lamoral, Alberta, August 6, 1918 (H. G. Dyar).
Banff, Alberta, July 8, 1918 (H. G. Dyar).
Laggan, Alberta, July 11, 1918 (H. G. Dyar).
Glacier, British Columbia, July 28, 1916 (C. G. Hewitt).
Kalso, British Columbia, June 11, 1903 (H. G. Dyar).
Prince George, British Columbia, May 9, 1919 (H. G. Dyar).
Terrace, British Columbia, August 12, 1919 (H. G. Dyar).
Salvus, British Columbia, May 27, 1919 (H. G. Dyar).
Kwinitsa, British Columbia, May 24, 1919 (H. G. Dyar).
Atlin, British Columbia, July 22, 1919 (H. G. Dyar).
Yukon Valley from Carcross to Dawson, July, 1919 (H. G. Dyar).

AEDES (HETERONYCHA) PIONIPS Dyar.

Aëdes pionips Dyar, Ins., Ins. Mens., vii, 19, 1919.

A large blackish mosquito. Mesonotum yellow, clear and even, rarely gray; two median black lines, broad and distinct and running far back; two short posterior lateral ones. Abdomen black, with basal segmental white bands, narrowed in the middle; venter whitish scaled, with more

or less black at the apices of the segments. Legs black, femora white below; knee-spots white. Wing-scales all black.

The colouration is not variable as far as observed; but the species is liable to be confused with large specimens of *lazarensis*. The winter is passed in the egg state, the larvae developing in early pools in spruce forest. The species is found only in the deepest forest or in northern regions. The males swarm after sunset in openings in the forest.

Distribution: Northern forests, presumably from Atlantic to Pacific, although no far eastern records are available, but not in the moist Pacific coast strip.

CANADIAN RECORDS.

White River, Ontario, June 17, 1918 (H. G. Dyar).
Kenogami River, Ontario, June 30, 1903 (W. J. Wilson).
Prince Albert, Saskatchewan, August 14, 1918 (H. G. Dyar).
Red Deer, Alberta, July 30, 1918 (H. G. Dyar).
Lochearn, Alberta, August 5, 1918 (H. G. Dyar).
Lamoral, Alberta, August 6, 1918 (H. G. Dyar).
Lake Louise, Alberta, July 11, 1918 (H. G. Dyar).
Prince George, British Columbia, May 9, 1919 (H. G. Dyar).
Terrace, British Columbia, August 12, 1919 (H. G. Dyar).
Kwinitsa, British Columbia, May 25, 1919 (H. G. Dyar).
Atlin, British Columbia, July 22, 1919 (H. G. Dyar).
Carcross, Yukon Territory, July 27, 1919 (H. G. Dyar).
Whitehorse, Yukon Territory, July 3, 1919 (H. G. Dyar).
Horse Falls, Yukon Territory, July 13, 1919 (H. G. Dyar).
Dawson, Yukon Territory, July 7, 1919 (H. G. Dyar).

AEDES (HETERONYCHA) IMPIGER Walker.

Culex impiger Walker, List Dipt. Brit. Mus., i, 6, 1848.
Aëdes decticus Howard, Dyar & Knab, Mosq. No. & Cent. Am. & W. I., iv, 737, 1917.

A small blackish mosquito. Head gray, with or without black spots. Mesonotum gray on the margins, more or less overspread with brown centrally, and with two median blackish stripes and short posterior lateral ones. Abdomen black, with rather broad basal segmental white bands, usually not narrowed centrally; venter whitish, with apical black segmental bands. Legs black, somewhat mixed with white scales especially below; femora white below. Wing-scales wholly dark. Palpi of the male with few or no white scales.

A description of the markings shows no difference from *lazarensis*; but

the habitus is characteristic, and when once learned, the species can generally be recognized. The markings vary in the extent of median brown shading, which may be absent; also the lines may be narrow or broad, even completely filling the mesonotum. The winter is passed in the egg state, the larvae developing in the earliest spring pools. The males swarm low, near the ground, in front of small bushes under trees.

Distribution: Northern forests from Atlantic to Pcaific, coming further south into the transitional zone than the two preceding species.

CANADIAN RECORDS.

White River, Ontario, June 25, 1907 (F. Knab).
Nipigon, Ontario, June 26, 1918 (H. G. Dyar).
Dryden, Ontario, June 27, 1918 (H. G. Dyar).
Kenora, Ontario, July 2, 1918 (H. G. Dyar).
Winnipeg, Manitoba, June 22, 1907 (F. Knab).
Winnipeg Beach, Manitoba, July 4, 1918 (H. G. Dyar).
Saskatoon, Saskatchewan, June 7, 1918 (A. E. Cameron).
Beaver Creek, Saskatchewan, June 3, 1918 (A. E. Cameron).
Red Deer, Alberta, July 30, 1918 (H. G. Dyar).
Lochearn, Alberta, August 5, 1918 (H. G. Dyar).
Lamoral, Alberta, August 6, 1918 (H. G. Dyar).
Banff, Alberta, August 16, 1903 (R. P. Currie).
Edmonton, Alberta, May 1, 1919 (H. G. Dyar).
Prince George, British Columbia, May 11, 1919 (H. G. Dyar).
Atlin, British Columbia, July 22, 1919 (H. G. Dyar).
Whitehorse, Yukon Territory, June 26, 1919 (H. G. Dyar).
Tahkeena River, Yukon Territory, July 19, 1919 (H. G. Dyar).
Hootalinqua, Yukon Territory, July 6, 1919 (H. G. Dyar).
Horse Falls, Yukon Territory, July 13, 1919 (H. G. Dyar).
Dawson, Yukon Territory, July 7, 1919 (H. G. Dyar).

AËDES (HETERONYCHA) PRODOTES Dyar.

Aëdes prodotes Dyar, Ins. Ins. Mens., v, 118, 1917.

A small blackish mosquito. Mesonotum gray, more or less or not at all overspread with dark brown centrally, sometimes almost completely dark brown, rarely with traces of median paired blackish lines. Abdomen black, with basal segmental white bands, rather broad and usually not narrowed centrally; venter whitish-scaled. Legs black with many white scales intermixed, especially below; femora white below. Wing scales black, often with white ones intermixed, especially along subcostal region. Palpi of the male with many white scales toward the tip of the long joint.

The mesonotal markings run into *impiger* on the one hand and into *intrudens* on the other. It is a small species, like *impiger*. The winter is passed in the egg state, the larvae developing in early spring pools. The females bite both by day and night. The males swarm high over spaces between bushes or small trees in open country.

Distribution: Northern Rocky Mountains to Alaska, rare, if at all in the east.

CANADIAN RECORDS.

Banff, Alberta, July 7, 1918 (H. G. Dyar).
Laggan, Alberta, July 11, 1918 (H. G. Dyar).
Lake Minnewanka, Alberta, July 22, 1918 (H. G. Dyar).
Lake Louise, Alberta, July 11, 1918 (H. G. Dyar).
Field, British Columbia, August 15, 1906 (H. G. Dyar).
Mt. Cheam, British Columbia, August 7, —— (J. Fletcher).
White Pass, British Columbia, July 28, 1919 (H. G. Dyar).
Atlin, British Columbia, July 22, 1919 (H. G. Dyar).
Carcross, Yukon Territory, June 26, 1919 (H. G. Dyar).
Whitehorse, Yukon Territory, June 26, 1919 (H. G. Dyar).
Tahkeena River, Yukon Territory, July 19, 1919 (H. G. Dyar).
Byer's Camp, Yukon Territory, July 6, 1919 (H. G. Dyar).
Big Salmon, Yukon Territory, July 15, 1919 (H. G. Dyar).
Carmack's, Yukon Territory, July 14, 1919 (H. G. Dyar).
Horse Falls, Yukon Territry, July 13, 1919 (H. G. Dyar).
Knudson's Camp, Yukon Territory, July 6, 1919 (H. G. Dyar).
Tantalus Mine, Yukon Territory, July 6, 1919 (H. G. Dyar).
Selkirk, Yukon Territory, July 13, 1919 (H. G. Dyar).
Dawson, Yukon Territory, July 7, 1919 (H. G. Dyar).

Group CANADENSIS.

AËDES (HETERONYCHA) CANADENSIS Theobald.

Culex canadensis Theobald, Mon. Culic., ii, 3, 1901.
Culex nivitarsis Coquillett, Proc. Ent. Soc. Wash., vi, 168, 1904.

A medium sized, dark brown mosquito, with conspicuously ringed tarsi. Mesonotum dark brown, with more or less distinct paired narrow light golden lines. Abdomen commonly unbanded dorsally, black, with triangular white lateral spots at the bases of the segments; venter whitish scaled. Legs black, the femora whitish beneath; tarsi with white rings involving both ends of the joints, broader on the hind tarsi, the last hind tarsal all white. Wing scales wholly dark.

The winter is passed in the egg state, the larvae developing in tran-

sient ground puddles, open woods pools and roadside ditches. The larvae will appear several times in a season, following successive filling of the pools by rain, but this probably does not indicate more than one annual generation, only that some of the eggs did not hatch at the first filling of the pool. The adults are persistent biters, being fond of attacking low, near the ground. The males swarm after sunset.

Distribution: Gulf States to southern Canada, westward in the warmer timbered country to British Columbia.

CANADIAN RECORDS.

St. John, New Brunswick, August 10, 1900 (W. McIntosh).
Younghall, New Brunswick, July 2, 1908 (A. Gibson).
Ottawa, Ontario, May 8, —— (J. Fletcher).
White River, Ontario, June 25, 1907 (F. Knab).
Nipigon, Ontario, June 26, 1918 (H. G. Dyar).
Dryden, Ontario, June 30, 1918 (H. G. Dyar).
Kenora, Ontario, July 2, 1918 (H. G. Dyar).
Jordan, Ontario, July 19, 1916 (E. Hearle).
Winnipeg Beach, Manitoba, July 4, 1918 (H. G. Dyar).
Oxbow, Saskatchewan, June 13, 1907 (F. Knab).
Saskatoon, Saskatchewan, August 10, 1918 (H. G. Dyar).
Prince Albert, Saskatchewan, August 14, 1918 (H. G. Dyar).
Red Deer, Alberta, July 30, 1918 (H. G. Dyar).
Lochearn, Alberta, August 5, 1918 (H. G. Dyar).
Lamoral, Alberta, August 6, 1918 (H. G. Dyar).
Banff, Alberta, July 19, 1918 (H. G. Dyar).
Lake Louise, Alberta, July 11, 1918 (H. G. Dyar).
Kalso, British Columbia, June 3, 1903 (H. G. Dyar).
Prince George, British Columbia, May 22, 1919 (H. G. Dyar).
Mission, British Columbia, Sept. 10, 1919 (E. Hearle).

Group CURRIEI.

AËDES (HETERONYCHA) CURRIEI Coquillett.

Culex curriei Coquillett, Can. Ent., xxxiii, 259, 1901.
Culex onondagensis Felt, Bull. 79, N.Y. State Mus., 278, 1904.
Aëdes quaylei Dyar & Knab, Journ. N.Y. Emt. Soc., xiv, 191, 1906.
Culex lativittatus Coquillett, Ent. News, xvii, 109, 1906.
Grabhamia mediolineata Ludlow, Can. Ent., xxxix, 129, 1907.

A rather small, yellowish gray mosquito, the tarsi banded with white, but sometimes very inconspicuously. Mesonotum creamy yellowish, a diffused brown stripe in the middle of variable width, and a little brown

on the lateral margins. Abdomen with grayish white basal segmental bands and a longitudinal mid-dorsal line, cutting the black ground into paired quadrate spots; venter pale, with median row of black spots. The pale scales on the abdomen vary, sometimes covering the whole surface. Legs black, with white scales intermixed, femora white below; tarsi with dull white rings at both ends of the joints. Wing-scales dark and whitish, rather evenly intermixed, though the third vein is predominatingly dark.

The winter is passed in the egg state, the larvae developing in early ground puddles. The males swarm after sunset over prominent objects on the prairie. The females are persistent biters, especially abundant after sunset.

Distribution: Dry, open country and prairie, central United States to Canada, also as a salt-marsh breeder on the coasts of the Atlantic, Pacific and Hudson's Bay.

CANADIAN RECORDS.

Moose Factory, Ontario, July 26, 1918 (H. N. Awrey).
Winnipeg Beach, Manitoba, July 4, 1918 (H. G. Dyar).
Wynyard, Saskatchewan, August 13, 1918 (H. G. Dyar).
Saskatoon, Saskatchewan, August 13, 1918 (H. G. Dyar).
Qu'Appelle, Saskatchewan, June 22, 1907 (T. N. Willing).
Oxbow, Saskatchewan, May 21, 1907 (F. Knab).
Carnduff, Saskatchewan, May 27, 1907 (F. Knab).
Banff, Alberta, July 8, 1918 (H. G. Dyar).
Vancouver, British Columbia, August 6, 1906 (Dyar & Caudell).
Qualicum, British Columbia, July 20, 1903 (J. Fletcher).
Duncans, British Columbia, August 8, 1906 (Dyar & Caudell).
Nanoose Bay, British Columbia, August 1, 1903 (J. Fletcher).
Caulfields, British Columbia, May 3, 1919 (E. Hearle).
Buccaneer Bay, British Columbia, August 24, 1919 (E. Hearle).
Victoria, British Columbia, August 29, 1919 (E. Hearle).

AËDES (HETERONYCHA) CAMPESTRIS Dyar & Knab.

Aëdes campestris Dyar & Knab, Journ. N.Y. Ent. Soc., xv, 213, 1907.
Aëdes callithotrys Dyar, Ins. Ins., Mens., viii, 16, 1920.

A rather large, yellowish gray mosquito, the tarsi banded with white, but sometimes very inconspicuously. Mesonotum creamy yellowish, a diffused brown stripe in the middle of variable width, and a little brown on the lateral margins. Abdomen with grayish white basal segmental bands, and a longitudinal mid-dorsal line, cutting the black ground into

paired quadrate spots; venter pale, with median row of black spots. The pale scales on the abdomen vary, sometimes covering the whole surface. Legs black, with white scales intermixed, femora white below; tarsi with dull white rings at both ends of the joints. Wing scales dark and whitish, rather evenly intermixed.

The winter is passed in the egg state; the larvae occur in alkaline pools with *curriei*. The males swarm after sunset close in the tops of small pine trees. The females bite by day or night, whenever one comes into their haunts.

Distribution: Utah and northward, very local, but usually abundant where it occurs.

CANADIAN RECORDS.

Charlton Island, James Bay, July 19, 1918 (H. N. Awrey).
Oxbow, Saskatchewan, June 18, 1907 (F. Knab).
Qu'Appelle, Saskatchewan, June 9, 1901 (T. N. Willing).
Carnduff, Saskatchewan, May 28, 1901 (T. N. Willing).
Regina, Saskatchewan, June 14, 1094 (T. N. Willing).
Kaslo, British Columbia, June 21, 1903 (H. G. Dyar).
Whitehorse, Yukon Territory, June 26, 1919 (H. G. Dyar).

Group STIMULANS.

AËDES (HETERONYCHA) STIMULANS Walker.

Culex stimulans Walker, List Dipt. Brit. Mus., i, 4, 1848.
Culicada subcantans Felt, Bull. 97, N.Y. State Mus., 448, 1905.
Aëdes mercurator Dyar, Ins. Ins. Mens., viii, 13, 1920.
Aëdes stimulans albertae Dyar, Ins. Ins. Mens., viii, 115, 1920.

A rather large brown mosquito with ringed legs. Mesonotum yellowish gray on the sides, a broad reddish brown or dark brown band in the middle, joining the short posterior stripes. Abdomen blackish, with basal segmental white bands, widening on the sides, and some white scales on the apices of the segments also; venter whitish, with a row of black dashes on middle line. Legs black, with many white scales intermixed on femora and tibiae, the tarsi with white rings at the bases of the joints, broad on the hind pair. Wings with black scales, many white ones intermixed, especially along costal region, but also on the other veins. In the Yukon Valley, the wing scales are wholly black (form *mercurator*). The form *albertae* shows larval differences. There are no reliable colour difference between this and *excrucians* and *fitchii*.

The winter is passed in the egg state, the larvae developing in spring pools, especially those which have been overflowed by high water. The males swarm after sunset over bushes, flying high and rapidly. This

species, with the other two mentioned, is common through the northern forests; but it is not possible to determine one from the other by the females alone, which makes exact records scarce.

Distribution: Northern forests, from Mississippi to the Rocky Mountains; Yukon Valley.

CANADIAN RECORDS.

Arnprior, Ontario, May —, 1917 (C. Macnamara).
Oxbow, Saskatchewan, June 7, 1907 (F. Knab).
Edmonton, Alberta, May 14, 1919 (H. G. Dyar).
Dawson, Yukon Territory, July 16, 1919 (H. G. Dyar).

AËDES (HETERONYCHA) CANTATOR Coquillett.

Culex cantator Coquillett, Can. Ent., xxxv, 255, 1903.

A medium sized brown mosquito, with very small tarsal rings. Mesonotum reddish brown, a little gray over the antescutellar space median and posterior-lateral bands faintly darker. Abdomen black, with dull white basal segmental bands, excavated centrally, the scales also somewhat diffused and occupying most of the last segment dorsally; venter whitish, with median black spots. Legs blackish brown, the femora white below; tarsi with very narrow white rings at the bases of the joints. Wing-scales wholly blackish.

Very much like *vexans* in colouration, but wholly unrelated thereto. The colouration of the abdomen furnishes the best differentiation.

The winter is passed in the egg state, the larvae developing in salt-marsh pools along the Atlantic littoral, several generations succeeding each other, according as the pools are filled by exceptionally high tides or rains. The females travel some miles inland, and become annoying far from their breeding-places. The mating habits of the males have not been described.

Distribution: Atlantic coast from New Jersey to Maine, probably in New Brunswick and Nova Scotia.

CANADIAN RECORDS.

None.

AËDES (HETERONYCHA) FLETCHERI COQUILLETT.

Culex fletcheri Coquillett, Proc. U.S. Nat. Mus., xxv, 84, 1902.

A large yellowish mosquito. Mesonotum dark yellow on the sides, a broad brown median band, contiguous to faint short posterior lateral stripes. Abdomen largely or wholly overspread with yellow scales, some-

times restricted to basal bands, but diffused and with scattered scales; venter yellowish, with black scales intermixed. Legs mostly yellow scaled, the tarsi black, with basal white rings on the joints, those on the hind legs large. Wings with the scales yellowish and black, the light ones predominating. In Ontario and British Columbia the form with banded abdomen occurs, but on the prairies, the abdomen is generally all yellow scaled.

The winter is passed in the egg state, the larvae developing in the larger ground pools on the prairie in early spring. The mating habits of the male have not been observed. The adults are not abundant, but occasionally met with on prairies and open woodlands.

Distribution: Canadian prairies, Minnesota[1] and Wisconsin.[1]

CANADIAN RECORDS.

Albany, Ontario, July 10, 1918 (H. N. Awrey).[1]
White River, Ontario, June 24, 1918 (H. G. Dyar).[1]
Nipigon, Ontario, June 26, 1918 (H. G. Dyar).[1]
Dryden, Ontario, June 30, 1918 (H. G. Dyar).[1]
Kenora, Ontario, July 2, 1918 (H. G. Dyar).[1]
Winnipeg Beach, Manitoba, July 4, 1918 (H. G. Dyar).[1]
Winnipeg, Manitoba, June 22, 1907 (F. Knab).
Aweme, Manitoba, June 1, 1904 (N. Criddle).[1]
Saskatoon, Saskatchewan, June 18, 1918 (A. E. Cameron).
Belonge Creek, Saskatchewan, July —, 1907 (V. A. Armstrong).[1]
Durs, Saskatchewan, June 19, 1918 (A. E. Cameron).
Dundum, Saskatchewan, July 15, 1917 (A. E. Cameron).[1]
Beaver Creek, Saskatchewan, July 17, 1917 (A. E. Cameron).[1]
Regina, Saskatchewan, June 23, 1902 (J. Fletcher).[1]
Pine Creek, Saskatchewan, July 12, 1903 (J. Fletcher).
Qu'Appelle, Saskatchewan, June 9, 1901 (J. Fletcher).
Carnduff, Saskatchewan, May 28, 1901 (J. Fletcher).
Oxbrow, Saskatchewan, June —, 1907 (F. Knab).
Prince Albert, Saskatchewan, August 14, 1918 (H. G. Dyar).[1]
Red Deer, Alberta, August 3, 1918 (H. G. Dyar).
Olds, Alberta, July 15, 1901 (J. Fletcher).[1]
Lochearn, Alberta, August 5, 1918 (H. G. Dyar).[1]
Lamoral, Alberta, August 6, 1918 (H. G. Dyar).[1]
Harrison, British Columbia, June 20, 1919 (E. Hearle).[1]
Agassiz, British Columbia, May 23, 1919 (E. Hearle).[1]
Mission, British Columbia, July 14, 1919 (E. Hearle).[1]
Mt. Cheam, British Columbia, August 3, 1899 (J. Fletcher).[1]

[1] No male; the record may refer to *riparius*.

AËDES (HETERONYCHA) RIPARIUS Dyar & Knab.

Aëdes riparius Dyar & Knab, Journ. N.Y. Ent. Soc., xv, 213, 1907.

A large yellowish mosquito. Mesonotum dark yellow on the sides, a broad brown band in the middle, contiguous to faint short posterior lateral stripes, the mesonotum more or less oversoread with brown. Abdomen blackish, with yellowish diffuse basal segmental bands and scattering pale scales; venter yellowish, with black scales intermixed. Legs mostly yellow scaled, the tarsi black, with basal white rings on the joints, those on the hind legs large. Wings with the scales dark, many yellowish ones intermixed.

The larva is unknown, and the habits of the males have not been observed. The adults occur in wooded prairie, but are so much like *fletcheri* as to be indistinguishable without males. The species requires further study, although evidently distinct.

Distribution: Canadian prairies, probably coëxtensive with *fletcheri* but has not been differentiated.

CANADIAN RECORDS.

Winnipeg, Manitoba, June 21, 1907 (F. Knab).

AËDES (HETERONYCHA) EXCRUCIANS Walker.

Culex excrucians Walker, Ins. Saund., 429, 1856.
Culex abfitchii Felt, Bull. 79, N.Y. State Mus., 381, 1904.
Culex siphonalis Grossbeck, Can. Ent., xxxvi, 332, 1904.
Aëdes sansoni Dyar & Knab, Can. Ent., xli, 102, 1909.
Aëdes euedes Howard, Dyar & Knab, Mosq. No. & Cent. Am. & W.I., iv, 714, 1917.

A rather large brown mosquito with ringed legs. Mesonotum yellowish gray on the sides, a broad reddish brown or dark brown band in the middle, joining the short posterior stripes. Abdomen blackish, with basal segmental white bands, widening on the sides, and some white scales on the apices of the segments also; venter whitish, with a row of black dashes on middle line. Legs black, with many white scales intermixed on femora and tibiae, the tarsi with white rings at the bases of the joints, broad on the hind pair. Wings with black scales, with more or less white ones intermixed, especially along costal region.

The adult females are not certainly distinguishable from *fitchii* or *stimulans*. This is commonly a larger species than *fitchii*, the sides of the mesonotum more shaded with brown, often completely so. The wing scales commonly have few or no white scales; but all the characters are intergradient, and not of diagnostic value. The larvae and male genitalia differ conspicuously in the three species.

The winter is passed in the egg stage, the larvae developing in early spring water, woods pools and marshes. There is but one annual generation, though the adults last most of the summer, flying in the woods. The species does not enter houses.

Distribution: Northern forests from New Jersey to Canada, westward to British Columbia, Yukon Valley and Alaska.

CANADIAN RECORDS.

Ottawa, Ontario, June 1, 1900 (J. Fletcher).
Trenton, Ontario, May 24, 1900 (J. Fletcher).
White River, Ontario, June 25, 1907 (F. Knab).
Dryden, Ontario, June 27, 1918 (H. G. Dyar).
Winnipeg, Manitoba, June 22, 1907 (F. Knab).
Red Deer, Alberta, July 29, 1918 (H. G. Dyar).
Banff, Alberta, July 7, 1918 (H. G. Dyar).
Whitehorse, Yukon Territory, July 2, 1919 (H. G. Dyar).

AËDES (HETERONYCHA) FITCHII Felt & Young.

Culex fitchii Felt & Young, Science, n.s., xx, 312, 1904.
Aëdes palustris Dyar, Ins. Ins. Mens., iv, 89, 1916.
Aëdes mimesis Dyar, Ins. Ins. Mens., v, 116, 1917.

A rather large brown mosquito with ringed legs. Mesonotum yellowish gray on the sides, a broad reddish brown or dark brown band in the middle, joining the short posterior stripes. Abdomen blackish, with basal segmental white bands, widening on the sides, and some white scales on the apices of the segments also; venter whitish, with a row of black dashes on middle line. Legs black, with many white scales intermixed on femora and tibiae, the tarsi with white rings at the bases of the joints, broad on the hind pair. Wings with black scales, with more or less white ones intermixed, especially along costal region.

The adult females are not certainly distinguishable from *excrucians* and *stimulans*. This species is commonly smaller than these and often has many white scales on the wings; the mesonotum is often clear gray on the sides, but none of the characters hold. The species is less closely addicted to forests than *excrucians*, being common on the prairies where some cover exists, and in the half-open country of the Yukon region. The males swarm as with *excrucians* and *stimulans*, there being no differences in these habits between the three.

The winter is passed in the egg state, the larvae developing in early spring water, often with *excrucians*. The adults fly until late in the season, not entering houses.

Distribution: Northern forests from the Atlantic to the Rocky Mountains, the moist Pacific strip (from *palustris*); Yukon Valley, Alaska, (from *mimesis*).

CANADIAN RECORDS.

White River, Ontario, June 25, 1907 (F. Knab).
Dryden, Ontario, June 27, 1918 (H. G. Dyar).
Winnipeg, Manitoba, June 22, 1907 (F. Knab).
Aweme, Manitoba, June 5, 1904 (N. Criddle).
Elkhorn, Manitoba, June 10, 1907 (T. N. Willing).
Saskatoon, Saskatchewan, June 7, 1918 (A. E. Cameron).
Prince Albert, Saskatchewan, June 10, 1918 (A. E. Cameron).
Oxbow, Saskatchewan, June —, 1907 (F. Knab).
Regina, Saskatchewan, June 10, 1904 (T. N. Willing).
Banff, Alberta, July 7, 1918 (H. G. Dyar).
Edmonton, Alberta, June 1, 1919 (H. G. Dyar).
Royal Oak, British Columbia, April, 1917 (R. C. Trehearne).
Dawson, Yukon Territory, July 20, 1919 (H. G. Dyar).

Group TRICHURUS.

AËDES (HETERONYCHA) TRICHURUS Dyar.

Culex trichurus Dyar, Journ. N.Y. Ent. Soc., xii, 170, 1904.
Culex cinereoborealis Felt & Young, Science, n.s., xx, 312, 1904.
Aëdes poliochros Dyar, Ins. Ins. Mens., vii, 35, 1919.

A large dark gray mosquito. Mesonotum gray on the sides, brown centrally and with brown posterior lateral stripes, but these markings not contrasted. Generally a small whitish space in front of the lateral stripes. Abdomen black, with broad basal segmental white bands, even; venter whitish-scaled. Legs black, the femora white towards base and nearly to tip below. Wing-scales black.

The winter is passed in the egg state, the larvae developing in early ground pools, leafy woods-pools and old road-side ditches. The mating habits of the males have not been observed. The adults fly in woods, but disappear early in the season. The name *trichurus* applies to the western form, *cinereoborealis* to the eastern, and *poliochros* to that in the wooded prairies. The eastern and western forms have larval differences the larvae of the prairie form are unknown.

Distribution: Southern fringe of the northern forests, Massachusetts to British Columbia.

CANADIAN RECORDS.

Ottawa, Ontario, May 6, 1900 (J. Fletcher).
Chelsea, Quebec, May 17, 1902 (A. Gibson).
Aweme, Manitoba, June 3, 1904 (N. Criddle).
Kalso, British Columbia, June 25, 1903 (H. G. Dyar).

Group NEARCTICUS.

AËDES (HETERONYCHA) NEARCTICUS Dyar.

Aëdes nearcticus Dyar, Rep. Can. Arctic Exp., iii, pt. C, 32, 1919.

A rather large black mosquito, with long hairy vestiture, especially conspicuous on under side of thorax. Mesonotum uniformly dark brown scaled, a little lighter on the margins; setae long. Abdomen black, with broad basal segmental white bands; venter whitish scaled. Legs black, the femora pale beneath. Wing-scales black.

The larvae develop in ground pools in the arctic regions. The habits of the males are unknown.

The species is closely allied to *innuitus* Dyar & Knab of Greenland and *alpinus* Linnaeus (=*nigripes* Zetterstedt) of Scandanavia. The three may prove to be one species; but the genitalia of the European form are undescribed.

Distribution: Arctic coast of Northwest Territory and Alaska.

CANADIAN RECORDS.

Bernard Harbour, Northwest Territories, July 9, 1915 (F. Johansen).
Dolphin and Union Strait, Northwest Territories, July 14, 1916 (F. Johansen).
Young Point, Northwest Territories, July 18, 1916 (F. Johansen).
Cape Bathurst, Northwest Territories, July 26, 1916 (F. Johansen).
Herschel Island, Yukon Territory, July 26, 1916 (F. Johansen).

Subgenus TAENIORHYNCHUS Lynch Arribalzaga.

AËDES (TAENIORCHYNCHUS) ATROPALPUS Coquillett.

Culex atropalpus Coquillett, Can. Ent., xxxiv, 292, 1902.

A small blackish mosquito. Mesonotum silvery gray on the sides; a dark brown median band, joining the short posterior lateral bands. Abdomen black, with even basal segmental white bands; venter white-scaled with black bands at the apices of the segments. Legs black, the femora whitish beneath; tips of femora and tibiae and tarsal joints at bases and apices narrowly white, the last hind tarsal all white. Wing scales all blackish.

The larvae live in holes in rocks along streams and the edges of lakes. The winter is passed in the egg state, the eggs fastened on the side of the rock. In summer generations, the eggs are scattered loosely. The adults are good biters in the vicinity of their breeding places which are necessarily very restricted, so that the species is never more than locally common. The mating habits of the males are unknown.

Distribution: Atlantic coast region from Virginia to New England; possibly in Mexico (*epactius* Dyar & Knab), and to be expected in southern Canada.

CANADIAN RECORDS.

None.

AËDES (TAENIORHYNCHUS) VARIPALPUS Coquillett.

Culex varipalpus Coquillett, Can. Ent., xxxiv, 292, 1902.
Taeniorhynchus sierrensis Ludlow, Can. Ent., xxxvii, 231, 1905.

A small blackish mosquito with white-ringed legs. Mesonotum dark brown, ornamented with a patch of light golden scales in front and a narrow line of the same from the lateral groove backward. Abdomen black, with basal segmental even white bands; venter whitish-scaled. Legs black, the femora white below; tips of femora and tibiae and the apices of the tarsal joints silvery white, involving the bases of the joints to a less extent; rings narrow, except on the hind legs, where they are broad, involving the whole of the last joint. Wing-scales wholly dark, thick and dense.

The larvae live in the water in holes in tree-trunks, occasionally in artificial receptacles. The winter is passed in the egg state; it is not known whether there is more than one annual generation. The females occasionally occur in annoying numbers in old forests, but are usually rare. The males form little swarms in the day time about some stationary warm-blooded animal, and mate with the females as these come to bite.

Distribution: Pacific coast region from southern California to British Columbia.

CANADIAN RECORDS.

Kalso, British Columbia, June 17, 1903 (H. G. Dyar).
Terrace, British Columbia, August 12, 1919 (H. G. Dyar).
Harrison, British Columbia, June 20, 1919 (E. Hearle).
Caulfields, British Columbia, July 19, 1919 (E. Hearle).
Vancouver, British Columbia, August 6, 1906 (H. G. Dyar).
Nanaimo, British Columbia, August 6, 1906 (Dyar & Caudell).

Wellington, British Columbia, August 8, 1906 (Dyar & Caudell).
Victoria, British Columbia, August 12, 1906 (H. G. Dyar).
Hope, British Columbia, May 20, 1919 (E. Hearle).
Deroche, British Columbia, June 13, 1919 (E. Hearle).
Mission, British Columbia, July 14, 1920 (H. G. Dyar).

AËDES (TAENIORHYNCHUS) SOLLICITANS Walker.

Culex sollicitans Walker, Ins. Saund., Dipt., 427, 1856.

A medium sized blackish mosquito with ringed legs. Mesonotum bronzy yellow, dark brown at the sides, the pleura white-scaled. Abdomen black with basal and median longitudinal bands of pale yellow, the lateral spots, medianly on the segments, white; venter yellowish, with some black scales toward the tips of the segments. Proboscis with a white ring. Legs black, the femora yellowish below; knee-spots white; tibiae with yellowish scales; tarsi black, the first tarsal with a yellowish central ring, the other joints white at base, broadly so on the hind pair. Wing-scales black and white, evenly mixed.

The larvae live in salt tidal pools on the coast. The winter is passed in the egg state, and there are as many generations in the year as conditions permit. The adults are locally abundant, and in such cases travel many miles inland.

Distribution: Coasts of Mexico, Gulf States, Antilles, Atlantic States to New England, probably in New Brunswick and Nova Scotia.

CANADIAN RECORDS.

None.

AËDES (TAENIORHYNCHUS) NIGROMACULIS Ludlow.

Grabhamia nigromaculis Ludlow, Geo. Wash. Univ. Bull., v, 85, 1907.
Grabhamia grisea Ludlow, Can. Ent., xxxix, 130, 1907.

A rather large blackish mosquito with ringed legs. Mesonotum bronzy yellow, a median dark brown band and dark brown at the sides, the pleura white-scaled. Abdomen black with basal and median longitudinal bands of dull yellowish, the lateral spots prolonged and of about the same shade as the dorsal markings; venter sparsely dull yellowish scaled. Legs black, femora, tibiae and first tarsal with many yellowish scales; femora sparsely black sprinkled below; tarsi black, with white rings at the bases of the joints, rather broad in the hind legs; knee-spots white. Proboscis with a white ring. Wing-scales black, a few whitish ones intermixed along the costa.

The winter is passed in the eggs state, the larvae developing in early

ground-pools in dry country. In the presence of irrigation, several generations may occur in the season, and the species become abundant. The females are severe biters. The males swarm after sunset over prominent objects on the prairie.

Distribution: Dry valleys and plains from Mexico and Arizona to Canada.

CANADIAN RECORDS.

Smoky, Alberta, August 24, 1915 (E. H. Strickland).

SUBGENUS FINLAYA Theobald.

AËDES (FINLAYA) TRISERIATUS Say.

Culex triseriatus Say, Journ. Acad. Nat. Sci. Phil., iii, 12, 1823.
Finlaya (?) *nigra* Ludlow, Can. Ent., xxxvii, 387, 1905.
Aëdes triseriatus hendersoni Cockerell, Journ. Econ. Ent., xi, 199, 1918.

A medium sized, black mosquito, with spotted abdomen. Mesonotum dark brown in the middle, the sides silvery white. Abdomen black dorsally, with silvery white lateral basal segmental spots; venter white-scaled, the posterior segments black-banded at apices. Legs deep black, the femora silvery white below. Wing-scales black.

The larvae live in the water in the holes in tree trunks, the winter being passed in the egg state. The females are severe biters, and, though never abundant, are often troublesome in dry woods. The habits of the males have not been observed.

Distribution: United States from the Gulf of Mexico to Montana, New England, and southern Canada.

CANADIAN RECORDS.

De Grassi Point, Ontario, June 23, July 4, 1917 (E. M. Walker).
Jordan, Ontario, August 3, 1916 (E. Hearle).

Subgenus ECCULEX Felt.

AËDES (ECCULEX) VEXANS Meigen.

Culex vexans Meigen, Syst. Beschr. Eur. zweifl. Ins., vi, 241, 1830.
Culex articulatus Rondani, Bull. Soc. Ent. Ital., iv, 30, 1872.
Culex malariae Grassi, Rend. della R. Accad. dei Lincei, 1899.
Culex sylvestris Theobald, Mon. Culic., i, 406, 1901.
Culex vagans Theobald, Mon. Culic., i, 411, 1901.
Culex nocturnus Theobald, Mon. Culic., iii, 159, 1903.
Culex montcalmi Blanchard, Les Moust., 407, 1905.
Culicada nipponii Theobald, Mon. Culic., iv, 337, 1907.

Culicada minuta Theobald, Mon. Culic., iv, 338, 1907.
Culex stenoetrus Theobald, Mon. Culic., iv, 395, 1907.
Culicada eruthrosops Theobald, Mon. Culic., v, 229, 1910.
Culex pseudostenoetrus Theobald, Mon. Culic., v, 343, 1910.
Culex hirsutum Ludlow (not Theobald), Psyche, xviii, 126, 1911.
Aëdes euochrus Howard, Dyar & Knab, Mosq. No. & Cent. Am. & W. I., iv, 716, 1917.

A medium sized to small brown mosquito. Mesonotum brown, a little paler about antescutellar space. Abdomen black, with narrow white basal segmental bands, tending to be notched on dorsal line; lateral spots separated therefrom, quadrate and elongate; venter whitish-scaled, with more or less distinct median blackish spots. Legs black, femora pale below; tarsi with very narrow white rings at the bases of the joints. Wing-scales wholly dark.

The winter is passed in the egg state, the larvae hatching in early ground pools, but also later in the season whenever the pools are filled by rain or otherwise. However, there may not be more than one annual generation. The females are severe biters in woods and thickets, not frequenting the open. The males swarm after sunset, sometimes in very large groups.

Distribution: North America, from the Mexican plateau to Canada, except on the Pacific coast and far north; Europe, northern Asia.

CANADIAN RECORDS.

Younghall, New Brunswick, July 4, 1908 (A. Gibson).
Ottawa, Ontario, June 18, 1906 (J. Fletcher).
White River, Ontario, June 24, 1907 (F. Knab).
Dryden, Ontario, June 27, 1918 (H. G. Dyar).
Kenora, Ontario, July 2, 1918 (H. G. Dyar).
Aweme, Manitoba, June 25, 1907 (N. Criddle).
Winnipeg, Manitoba, June 22, 1907 (F. Knab).
Winnipeg Beach, Manitoba, July 4, 1918 (H. G. Dyar).
Moose Jaw, Saskatchewan, August 24, 1906 (Dyar & Caudell).
Saskatoon, Saskatchewan, August 10, 1918 (H. G. Dyar).
Prince Albert, Saskatchewan, August 14, 1918 (H. G. Dyar).
Red Deer, Alberta, August 1, 1918 (H. G. Dyar).
Lochearn, Alberta, August 7, 1918 (H. G. Dyar).
Lamoral, Alberta, August 6, 1918 (H. G. Dyar).
Calgary, Alberta, July 28, 1918 (H. G. Dyar).
Lake Minnewanka, Alberta, July 22, 1918 (H. G. Dyar).
Banff, Alberta, July 7, 1918 (H. G. Dyar).
Kalso, British Columbia, June —, 1903 (H. G. Dyar).

Ainsworth, British Columbia, June 10, 1903 (R. P. Currie).
Prince George, British Columbia, September 7, 1919 (H. G. Dyar).
Mission, British Columbia, June 12 to October 9, 1919 (E. Hearle).
Chilliwack, British Columbia, July 3, 1919 (E. Hearle).
Whonnock, British Columbia, July 23, 1919 (E. Hearle).

Subgenus AËDES Meigen.

AËDES (AËDES) CINEREUS Meigen.

Aëdes cinereus Meigen, Syst. Beschr. Eur, zweifl. Ins., i, 13, 1818.
Culex nigritulus Zetterstedt, Dipt. Scand., ix, 3459, 1850.
Aëdes fuscus Osten Sacken, Bull. U.S. Geog. Surv., iii, 191, 1877.
Culex pallidohirta Grossbeck, Can. Ent., xxxvii, 359, 1905.
Culex pallidocephala Theobald, Mon. Culic., v, 612, 1910.

A rather small blackish mosquito. Mesonotum dark brown. Addomen black, with a continuous lateral white line, but also with this line broken into spots and with more or less distinct basal segmental white bands; venter whitish scaled. Legs black, the femora whitish beneath. Wing-scales all dark. The male has short palpi as in the female and is easily recognized thereby.

The winter is passed in the egg state, the larvae developing in early spring pools, but also, following rains, during the summer. The later emergencies are less numerous. The females are good biters in woods and thickets, not coming into the open. The males swarm after sunset in openings between willows and similar locations.

Distribution: Northern North America and northern Europe.

CANADIAN RECORDS.

White River, Ontario, June 18, 1918 (H. G. Dyar).
Dryden, Ontario, June 29, 1918 (H. G. Dyar).
Kenora, Ontario, July 2, 1918 (H. G. Dyar).
Winnipeg Beach, Manitoba, July 4, 1918 (H. G. Dyar).
Winnipeg, Manitoba, June 22, 1907 (F. Knab).
Saskatoon, Saskatchewan, August 12, 1918 (H. G. Dyar).
Prince Albert, Saskatchewan, August 14, 1918 (H. G. Dyar).
Oxbow, Saskatchewan, June 17, 1907 (F. Knab).
Red Deer, Alberta, July 29, 1918 (H. G. Dyar).
Lochearn, Alberta, August 5, 1918 (H. G. Dyar).
Lamoral, Alberta, August 6, 1918 (H. G. Dyar).
Calgary, Alberta, July 28, 1918 (H. G. Dyar).
Lake Minnewanka, Alberta, July 22, 1918 (H. G. Dyar).

Banff, Alberta, July 7, 1918 (H. G. Dyar).
Kalso, British Columbia, June 11, 1903 (H. G. Dyar).
Agassiz, British Columbia, June 20, 1919 (E. Hearle).
Dewdney, British Columbia, June 6, 1919 (E. Hearle).
Mission, British Columbia, June 23, 1919 (E. Hearle).
Chilliwack, British Columbia, July 3, 1919 (E. Hearle).
Nicomen Island, British Columbia, August 4, 1919 (E. Hearle).
Prince George, British Columbia, September 9, 1919 (H. G. Dyar).
Terrace, British Columbia, August 11, 1919 (H. G. Dyar).
Salvus, British Columbia, June 7, 1919 (H. G. Dyar).
Kwinitsa, British Columbia, June 1, 1919 (H. G. Dyar).
Atlin, British Columbia, July 23, 1919 (H. G. Dyar).
Whitehorse, Yukon Territory, June 29, 1919 (H. G. Dyar).
Horse Falls, Yukon Territory, July 13, 1919 (H. G. Dyar).
Dawson, Yukon Territory, July 10, 1919 (H. G. Dyar).

Genus URANOTAENIA Lynch Arribalzaga.

A small genus, mainly of tropical distribution. The larvae live in ground pools, and have a superficial resemblance to *Anopheles*, from the elongated black head, and the habit of lying flat in the water, although the larvae are not surface-feeders. The adults are ornamented with lines of metallic blue scales.

URANOTAENIA SAPPHIRINUS Osten Sacken.

Aëdes sapphirinus Osten Sacken, Trans. Am. Ent. Soc., ii, 47, 1868.

A small blackish mosquito. Mesonotum brown, thinly scaled, a narrow line of metallic blue scales to the scutellum; a lateral line on each side, running to the wing. Abdomen black above; venter grayish. Legs black, femora pale beneath; tips of femora and tibiae with a pearly white spot. Wing-scales all dark.

The winter is probably passed in the adult state. Eggs are laid in boat-shaped masses floating on the water. The females are not troublesome. I have no certain records of the biting. The habits of the males are unknown. A rare species, seldom seen unless bred.

Distribution: Eastern United States from the Gulf of Mexico to northern New England, possibly in southern Canada.

CANADIAN RECORDS.

None.

Genus ANOPHELES Meigen.

A genus of world-wide distribution, although not very numerous in species, most abundant in the tropics. The females have long palpi like the males, an elongate mesonotum and very long legs. Many of the species are the intermediate host of the malarial parasite of man. The winter is passed as adult, the eggs being laid singly on the surface of water. They are provided with little floats, which differ in shape in the different species.

Anopheles was divided into many genera on characters of vestiture by F. W. Theobald. Subsequent study has led to the rejection of most of these; but it has been suggested that they may be retained as subgenera. The Canadian species all belong to *Anopheles* proper.

KEY TO THE CANADIAN SPECIES OF ANOPHELES.

1. Wings with a white spot at outer third of costa.....*punctipennis* Say
   Wings without such a white spot.....2
2. Palpi blackish throughout.....3
   Palpi with dull silvery white rings at the bases of the joints, *walkeri* Theobald
3. Wing at apex with a coppery spot on the fringe, *occidentalis* Dyar & Knab
   Wing-fringe uniformly dark.....*quadrimaculatus* Say

ANOPHELES (ANOPHELES) PUNCTIPENNIS Say.

Culex punctipennis Say, Jour. Acad. Nat. Sci. Phil., iii, 9, 1823.
Culex hyemalis Fitch, Am. Journ. Agr. & Sci., v, 281, 1847.
Anopheles perplexens Ludlow, Can. Ent., xxxix, 267, 1907.

Mesonotum elongate, hairy, broadly whitish in the integument in the middle, dark brown on the sides. Abdomen hairy, brown, the apices of the segments darker, in the integument. Legs long and slender, blackish; tips of femora and tibiae with small white spots. Wings with the scales black except in certain spots as follows: a large one at outer third of costa and a smaller one at apex, both involving second vein; one on third vein in the cell, on the stem and middle of both forks; at base and middle of fifth vein.

The larvae are surface-feeders in all sorts of water-puddles, often in small or temporary rain-puddles, but also in permanent water. The males swarm after sunset.

Distribution: United States from Mexico northward, except the dry central region, reaching Canada at both coasts.

CANADIAN RECORDS.

Ottawa, Ontario, August 16, 1900 (A. Gibson).
Winona, Ontario, August 16, 1916 (E. Hearle).
Jordan, Ontario, July 17, 1916 (E. Hearle).
Guelph, Ontario, November 29, 1919 (E. Hearle).
Nanaimo, British Columbia, August 6, 1906 (Dyar & Caudell).
Duncans, British Columbia, August 9, 1906 (Dyar & Caudell).
Wellington, British Columbia, August 7, 1906 (Dyar & Caudell).
Mission, British Columbia, July —, 1919 (E. Hearle).
Yarrow, British Columbia, March 25, 1919 (E. Hearle).
Ladner, British Columbia, April 5, 1919 (E. Hearle).
Hope, British Columbia, May 21, 1919 (E. Hearle).

ANOPHELES (ANOPHELES) OCCIDENTALIS Dyar & Knab.

Anopheles occidentalis Dyar & Knab, Proc. Biol. Soc. Wash., xix, 159, 1906.

Mesonotum elongate, hairy, broadly whitish in the integument in the middle, dark brown on the sides. Abdomen with light hairs, brown, the apices of the segments darker, in the integument. Legs long and slender, blackish; tips of femora and tibiae whitish. Wings with the scales black, forming four dark spots by being thickly placed as follows: base of second vein in the cell; on the cross-veins and forks of second and fourth veins. Tip of the wing with a brassy reflection in the fringe.

The larvae are surface-feeders in all sorts of water-puddles, preferring permanent water. The habits of the males have not been observed. The difference between this and *quadrimaculatus* is slight.

Distribution: Western United States except the moist northern Pacific strip, eastward through Canada to northern Maine.

CANADIAN RECORDS.

Ottawa, Ontario, September 30, — (J. Fletcher).
Guelph, Ontario, November 29, 1919 (E. Hearle).
Little Current River, Ontario, July 18, 1903 (W. J. Wilson).
Nagagami River, Seventh Portage, Ontario, June 7, 1903 (W. J. Wilson).
Kenora, Ontario, July 2, 1918 (H. G. Dyar).
Aweme, Manitoba, April 23, 1905 (N. Criddle).
Revelstoke, British Columbia, August 22, 1903 (H. G. Dyar).
Mission, British Columbia, July 22, 1919 (E. Hearle).
Chilliwack, British Columbia, July 3, 1919 (E. Hearle).
Nicomen Island, British Columbia, June 23, 1919 (E. Hearle).
Hootalinqua, Yukon Territory, July 6, 1919 (H. G. Dyar).
Valley of Mayo River, Yukon Territory, ———, 1904 (J. Keele).

ANOPHELES (ANOPHELES) QUADRIMACULATUS Say.

Anopheles quadrimaculatus Say, Keat. Narr. Exp. St. Peter's Riv., ii, 356, 1824.

Anopheles guttulatus Harris, Hitch Rep. Geol. Min. Bot. Zool. Mass., 595, 1835.

Anopheles annulimanus van der Wulp, Tidj. voor Ent., x, 129, 1867.

Mesonotum elongate, hairy, broadly whitish in the integument in the middle, dark brown on the sides. Abdomen with light hairs, brown, the apices of the segments darker, in the integument. Legs long and slender, blackish; tips of femora and tibiae whitish. Wings with the scales black, forming dark spots by being thickly placed as follows: Base of second vein in the cell; on the cross-veins and forks of second and fourth veins.

The larvae are surface-feeders in water-puddles, especially permanent water connected with rivers. The habits of the males have not been observed.

Distribution: Mexico to New England and Canada, east of the Rocky Mountains.

CANADIAN RECORDS.

St. Catherines, Ontario, August 24, 1916 (E. Hearle).
Jordan, Ontario, August 4, 1916 (E. Hearle).

ANOPHELES (ANOPHELES) WALKERI Theobald.

Anopheles walkeri Theobald, Mon. Culic., i, 199, 1901.

Palpi with small white rings at the bases of the joints. Mesonotum dark brown, uniformly coloured. Abdomen blackish, with brown hairs. Legs long and slender, black, the femora pale below; small white spots at tips of femora and tibiae. Wing-scales black, not forming distinct spots, though sometimes slight ones at the bases and forks of second and fourth veins.

The larvae inhabit water formed by overflows from rivers, which occasionally goes dry. The habits of the males are unknown. It has not been demonstrated whether this species carries malaria.

Distribution: Eastern North America.

CANADIAN RECORDS.

Lake Simcoe, Ontario, September —, —— (E. M. Walker).
Ottawa, Ontario, August 23, 1900 (A. Gibson).

GOVERNMENTAL RESEARCH

By George K. Burgess, Sc.D.
Chief, Division of Metallurgy, Bureau of Standards, Washington, D.C.

As an aftermath of war, the past two years have witnessed an unparalleled interest of world wide extent in the subject of scientific research, embracing its aims, scope and methods, as well as its relation to industry, university and government. A remarkable series of contributions and addresses, written mainly by leaders in, or directors of research, have called attention to the various aspects of the subject and have served to inform the public mind and stimulate it to a realization of the importance of research to the community on the one hand and the dangers which attend ill considered plans on the other.

One of the most important forums for discussion of this fundamental subject has been the Royal Canadian Institute and I would like to recall, in this connection, particularly, the addresses before this Institute of Dr. George E. Hale on "Co-operation in Research" and Dr. Frank B. Jewett on "Industrial Research". It so happens that Messrs. Hale, Jewett, and myself have been identified each with a separate and distinctive phase of the development of research; Dr. Hale, with science unalloyed with industrial aspects or governmental control, Dr. Jewett with the applications of Science to an industry, and the writer (speaker) with scientific research in a government department. The preliminary training of each of us was remarkably similar; we all are graduates of the Massachusetts Institute of Technology, specializing in physical science and all had supplementary university training and some teaching experience, since which each has made his life's work in his chosen field of research of the three characteristic types, institutional, industrial, and governmental. We are all therefore exponents of the group method of carrying on research.

As a representative of this third type, that is, of research under government auspices, it may not be without interest to you to have from me a statement regarding the conduct of research in a Government Laboratory. I can of course do no better than give you the impression I have received from the development of the laboratories with which I am associated, those of the Bureau of Standards, and especially in their relation to the public and the government in my own field of metallurgy.

I would first however call to your attention the tendency toward a somewhat different orientation of the relations of government to scientific research in the two countries that are most intimately related in blood and institutions to Canada, namely Great Britain and the United States.

The relations of the British Government to research are set forth with great completeness in the annual reports of the Committee of the Privy Council for Scientific and Industrial Research and are ably summarized by Sir Frank Heath in an address before the Society of Arts on "The Government and the Organization of Scientific Research.[1] The cardinal principles which have guided the development of this trust are set forth in Privy Council Committee's Report of 1918-19 and will bear repeating:

"We believe, in the first place, that while it is possible for the State by means of suitable grants to individuals or the generous support of universities and other independent institutions for research to encourage the pursuit of research in pure science, it is dangerous and even fatal to attempt to organize it. Research of this nature has no other aim than the creation of new knowledge and is impatient of the control which is inseparable from the idea of external organisation. On the other hand, it is necessary for the modern State to organize research, including those simpler types of research which we may call investigation, into problems which directly affect the well-being of large sections of its people. Such researches and investigation, deal either with applied science or if they are conducted in the realm of pure science are undertaken with a specific end in view. . . ."

"But, in the second place, if the organization of research for public purposes is to be effective and economical it is necessary to arrange for a central clearing house which will be cognizant of the general lines of research undertaken by different Departments of Government, and a central body connected therewith capable of undertaking or organizing research which it is agreed can best be conducted by one agency in the interests of all."

"In the third place, it is dangerous and even fatal under peace conditions for the State to attempt to conduct researches and investigations for the immediate benefit of industries which are not under State management. Industrial research is as integral a part of production or distribution as advertisement or insurance. But this does not preclude the State from encouraging the organization of research within an industry by means of grants-in-aid made under suitable conditions, or even by means of preliminary demonstrations of the valuable results which a well-conducted research may be expected to secure."

[1] Sir Frank Heath, Jl. Roy. Soc. Arts, February 21, 1919.

"Finally, it would be fatal to the success of a Department entrusted with the encouragement and organization of research to concern itself with exploitation or commercial development or administrative application of the results which may be obtained. . . ."

It should be noted also that the English plan separates the administrative functions from the technical or scientific, the policies and programs of the latter being exclusively under the control of advisory committees composed of scientific or technical experts who are not members of the Department.

In the United States, the major branches of scientific research under governmental jurisdiction have not been gathered together under a single administrative head as in England but have been left each to the independent direction of the department of state in which it may be accidentally located, although there is now under consideration a measure that would group all the engineering and many of the scientific bureaus, except those dealing with agriculture, under a single Department of Public Works. The direction of scientific work, as at present organized, is almost exclusively in the hands of scientific men who combine the functions of an administrator and leader in research.

The American plan of independent administrative units does not mean that there are not often very intimate relations between scientific services in the various government departments including interchange of programs, partition of projects between them and other forms of cooperation maintained by a sufficiently close liaison, either formal or informal; although it could hardly be maintained that this common effort is as effective in all cases as could be wished. Again, certain scientific and technical services, such as the Advisory Committee for Aeronautics, are specifically constituted by law to include a membership from the several interested departments and the research work of this Committee is distributed among them. This method of bringing together the representatives of several branches of the service, some dealing with the application and others with the solution of scientific problems in a definite field of research, makes for better understanding between theory and practice, and the scientific workers have the benefit of valuable advice from the men who are to use the results of the investigation. This constant interplay is beneficial to both. This method of joint research control could be extended with advantage to many other fields of the applications of science in which the government is interested.

One of the most important and fundamental fields of general interest, in which a beginning has been made to bring the departments together, is that of standardization and specifications. It has been proposed to

make the Bureau of Standards a clearing house of information—to use the British term—on those subjects for the government. There are great possibilities here for realizing economies in purchases and improvements in design and there will also result inevitably a considerable impetus to scientific research, especially on fundamental constants and properties of materials which form the basis of constructing standards and writing specifications. The formation of the American Engineering Standards Committee, in which the Departments of Commerce, Navy, and War are represented and which is now working in a highly satisfactory manner, forms a further liaison with the public through the Engineering Societies, which again makes for development and improvement in many domains tributary to scientific research.

In looking over the multiplicity of research projects supported by the United States Government, one might easily get the impression that with such a widely scattered responsibility, as actually exists, for the planning of research in the various government departments, there might arise considerable confusion and duplication. A careful survey of the situation, however, would soon convince one of the surprisingly slight amount of overlapping in the scientific work among the several departments. I can speak with some positiveness on this subject as I have been recently occupied in such a survey as a member of a Board which has just completed a study of duplication in the scientific work carried on by the government; and it is a fact that the actual duplication is almost non-existent.

Although there are in the United States for certain lines of governmental scientific research, such formal or informal advisory technical committees as mentioned above, the role of initiation, correlation and stimulation of research, including industrial scientific research, taken in England by the Department of Scientific and Industrial Research, has been, in the United States largely assumed within the past year or two by the National Research Council, the organization and scope of which have been so ably set forth before this Institute by its first Chairman, Dr. Hale.

The impetus given in England by the Government to the organization and support of Research Associations has been, it seems to me, one of the most remarkable of recent achievements in the successful intervention by a government for the encouragement of national industries by aiding in the formation of a type of organization by which the industries can best help themselves. The crucial test of this method of stimulating industrial research will in all probability come after the five years time limit of government support is reached when the Research Associations will have to shift for themselves.

The Research Council has been endeavouring to foster in the United States the formation of somewhat similar co-operative scientific research associations among several of the American industries, but to this date, it would appear safe to say, with but indifferent success. It is perhaps not too early to ask, why does the formation of such Research Associations readily succeed in Great Britain and apparently not in the United States? Is it because of government initiative and support that they are established so promptly in England and would they be eventually in the United States if such support were forthcoming? Is it, that in the United States the industries are already provided with all the research assistance they need or can make use of? Or on the other hand, can it be argued our industrial leaders are not yet convinced of the value of this type of co-operative research? I do not venture to answer these questions, replies to which in the last analysis may be but a formulation of underlying national characteristics; but possibly you in Canada by your solution of the problem will help shed light that will aid us all.

What has been the policy of the Government of the United States toward scientific research and its applications to the industries of the country? To put the question is to call forth immediately, what is familiar to you all, the response that in many fields notably in the agricultural sciences the Government has been the most generous of sponsors. It is also supporting research in almost all domains of pure and applied science from astronomy and mathematics to metallurgy and road construction, and in many other branches than agricultural research it has been the pioneer and still is the leader. Moreover, in recent years, there has been a marked advance in governmental support of scientific research fundamental to industry, particularly as exemplified by the Bureaus of Mines and of Standards.

So much has been written recently about the advantages, including atmosphere, surroundings and status of research conducted under university or institutional guidance on the one hand and in industrial establishments on the other hand, and so little has been said—and silence may appear to be more eloquent than speech under certain conditions—of the advantages of research under governmental auspices, that it is difficult to resist setting forth here some of the conditions, as I see them, of research in a government department and of the position of the scientific man in the government service.

If government service, which we must remember is service for the public, is so unattractive, as certain writers have intimated, why for instance has the senior scientific staff of the Bureau of Standards remained nearly intact from its foundation some twenty years ago? There must be some other than pecuniary advantage to account for this

stability of position among scientific leaders, which has been the rule, rather than the exception, until very recently in most of the scientific establishments of the American government. The present moment, marked by scientific men leaving the government service in unprecedented numbers, may be accounted for primarily by the bidding for their services by industries and institutions that have been able to readjust their salary scales to meet the mounting cost of living more promptly than has the government. It is within reason to suppose however that this situation will be eventually readjusted.

What then are some of the advantages to the scientific man of his position in the government service as compared with the university man or the man in a research laboratory pertaining to industry? The attributes the research worker most cherishes are freedom for development within his chosen field; unhampered opportunity to publish the results of his discoveries; the stimulation afforded by the congenial atmosphere of sympathetic and critical co-workers; an absence of extraneous, irksome tasks; in the existence and maintenance of the ever changing material facilities for research. Taking the Bureau of Standards as a type of governmental institution devoted largely to scientific research, I can state from experience I know of no other type where these desirable attributes are more happily blended than here.

There is also the added satisfaction, or privilege if you will, the "government scientist" possesses, in that he is conscious of working directly for the public welfare in response to a public demand, expressed through the representatives of the people in Congress by their allotment of funds to support his work. This direct relation to the public—and it is much more intimate than many persons realize—gives him a pride and confidence in his accomplishments that cannot be had by one working solely for himself and his science or for an industry or commercial firm. His sense of responsibility is enhanced and he will plan his work accordingly. As he demonstrates his ability to make efficient use of it, his freedom of choice of subjects is almost unlimited, and he has absolute liberty as to his methods of attacking the problems he sets out to solve. I wonder if more can be said for any other type of research centre?

The craving to communicate his ideas and exhibit his work to others is a well known trait of the scientific man. Among the hundreds, nay thousands of investigators in the industrial research laboratories the ideals of which have been outlined by Messrs. Jewett, Mees,[1] Carty, Nutting, how many of these men have the opportunity of free communion with others? On all important problems—important from the technical,

[1]C. E. K. Mees, the Organization of Industrial Scientific Research, McGraw Hill, 1920, contains an excellent bibliography of recent titles.

competitive point of view—absolute silence is usually the most rigid of pass words. What might become many able contributions to science never see the light of day, on account of, what appears to me, a misguided policy of secrecy which often extends to unessentials, from the manufacturer's point of view, in an industrial research laboratory. The following is an illustration among many: the director of a long established industrial research laboratory showed me the other day the reports on a series of long since completed but as yet unpublished investigations of considerable general interest, two of which had just been duplicated and published by the Bureau of Standards where we had no knowledge of the previous work. In addition to the economic waste of unnecessary duplication, what is the effect on the morale of the men who did the work first and had it suppressed except for use in the plant?

The benefits of association and working in a community of considerable size where there may be rapid interchange and immediate availability of information and experimental facilities are often overlooked by those who advocate the advantages of research by lone individuals in the conditions of practical isolation often prevailing in even our larger universities. The laboratories of the government, and to a less extent the larger industrial laboratories, should be and unquestionably are able to secure more rapid progress and greater effectiveness in the execution of research than can the isolated worker.

Then as to the facilities or tools of research, the public laboratories, speaking generally, are better equipped than most private laboratories although some of the industries maintain laboratories before which even the government laboratories pale. The industrial research laboratories to be effective must also possess as adjuncts development laboratories for manufacturing on an experimental scale. In pure science there are many problems, often the most fundamental such as the exact determination of physical constants and standards, which require very elaborate and costly layouts and often take a series of years for their completion. Such can best be left to the government laboratories.

It would thus appear that viewed from these various standpoints of freedom, publication, facilities, atmosphere, so dear to the research worker he is at least as well off in the government laboratory as elsewhere.

As an example of the operation of a government research laboratory in the United States, let us take the Division of Metallurgy of the Bureau of Standards. What does it do and how?

First as to organization; the Bureau is divided for administrative convenience into twelve divisions, the office, the plant, the shops, and nine scientific or technical divisions, each constituting one of the branches of scientific work carried out at the Bureau, electricity, optics, heat,

chemistry, weights and measures, metallurgy, engineering physics, structural materials, ceramics. Each division is again divided into sections; thus in metallurgy there are sections of: 1. Microscopy and Structure of Metals, 2. Heat Treatment and Thermal Analysis, 3. Working and Miscellaneous Properties, 4. Chemical Metallurgy, 5. Foundry.

The methods of directing and conducting the research work within the division, we may mention briefly. There are no rules and regulations. Funds are allotted to the Division either by direct appropriation of Congress for a specific purpose or from the general funds of the Bureau by the Director. Each research is authorized by the Director on the written advice of the Division Chief. At meetings of the leaders within the Division the programme of work is considered and as a result of these discussions supplemented by written estimates the divisional budget is made up. Frequent conferences of the leaders are held to determine questions of policy and the progress of the work is fully discussed. Occasional meetings of the separate sections are also held, and there are also constantly being held informal conferences of members of the staff interested in any problem. The whole Division meets once in two weeks when a formal presentation of some investigation is given by its author. Each member of the Division presents a monthly progress report in writing. The papers offered for publication are reviewed critically by a Committee of experts within the Bureau. A personnel committee consisting of all Chiefs of Division passes on most promotions.

In addition to the regular staff we occasionally have guests, often from abroad, who usually spend several months with us on some research problem. We are glad also to welcome representatives of industrial laboratories who stay with us long enough either to get acquainted with our methods and technique or to carry out some research for which our facilities may be especially adapted. It is hoped a system of industrial fellowships, which is being tried tentatively may become well established; this is expected, to aid greatly in developing research men for the industries.

The supervision of the routine work of testing and standardization is carried out by the leaders in research covering the same subject. There may or may not be a distinction between the personnel engaged in testing and research depending upon circumstances. This arrangement makes for flexibility, and avoids invidious distinctions and has worked extremely well. Men showing an aptitude for research have the opportunity to show it even if they may be assigned originally to routine work, and conversely. The skeleton of the organization is however of little importance as compared with its spirit. The Bureau of Standards con-

sists above all of men and women imbued with high ideals and is a living organism of the highest type.

The Division of Metallurgy was formed in July, 1913, and has grown in population from one to fifty-seven and has acquired a very complete equipment to meet the needs of metallurgical research and testing. Over the development of testing we have no immediate control. The public and the government departments send us what they will and we try to satisfy their demands. It is a remarkable fact worthy of note that whenever a new line of testing is announced, immediately there is set up a never ceasing flow of materials or instruments for test, the volume of which is oftentimes embarrassing; and in consequence one of our most difficult problems is to adjust equitably our efforts as between the execution of tests, our routine work, and the carrying out of investigations, our preferred work of at least equal urgency. There is here of course the ever present danger of too easily choosing the immediate for the permanent. Although not so vociferously expressed the real demand for knowledge concerning fundamental constants and properties is at least as great as the need expressed in the polite but insistent requests for the report on a trivial test of a material of interest to but one party. We are obliged to remind ourselves at times that we are here to serve the best interests of the public in our several domains of science.

The field covered by our metallurgical researches and investigations embraces subjects confined mainly to what has been called products metallurgy as distinguished from what is called process metallurgy which latter is illustrated by the reduction of metals from their ores, the field of the Bureau of Mines.

As one of the subjects of metallurgical research which will undoubtedly have far reaching consequences, mention may be made of the study of gases in steel, including the development of methods of analysis; the determination of the quantity and manner of inclusion of the several gases which may be present such as oxygen, nitrogen, hydrogen and the oxides of carbon; and the characteristic gas content for steels of different composition and as determined by the method of manufacture. An immediate application of the methods here employed has been developed in our investigation of steel welding methods and products. The clearing up of the behaviour of welded metal as influenced by its gas content will aid greatly in solving some of the difficult problems connected with the welding art.

We were greatly concerned during the war with the scarcity, real or threatened, of several minerals and metals of vital necessity to the industries of the country. Among these were manganese, tin and platinum, and it became necessary to modify manufacturing processes and

devise suitable substitutes. We did a great deal of research work along these lines. Thus in the case of tin for example, which is all imported, we developed a satisfactory solder containing only ten per cent. of tin instead of the usual 40 or 50 per cent. This solder containing also 80 per cent. lead and 10 per cent. cadmium was as cheap as ordinary solder. The tin content of bearing metals for most uses, it was shown, could be very greatly reduced, and for the tin bronzes satisfactory alloys, made of available metals, were substituted. In fact, I believe America could have carried on with some ten per cent. of the normal tin consumption.

A great deal of attention is given constantly to questions connected with the various types of failure of metals and metal products such as flaky steel and internal fissures in railroad materials and stress corrosion in structural bronzes, to mention but two types, and numerous papers on these subjects have been published by the staff. The various and puzzling aspects of the corrosion of metals also has constant attention.

There is now under way a series of investigations on special steels including structural steels, high speed steels and their substitutes, high chromium steels of various types, and of steels containing unusual elements.

Some of the other subjects of metallurgical research are copper crusher gages for testing powder, improvement of machine gun barrels to resist erosion, identification tags for the Army and Navy, spark plug electrodes, characteristics of bearing metals, metals for aeronautical instruments, centrifugal steel castings, comparison of ingot practice in steel manufacture, temperature control of metallurgical manufacturing operations, embrittling of thin steel parts by cleaning, pickling, and plating, standard test bars for various alloys, and many other matters.

I shall not tire you, however, with an enumeration, much less with a description, of each of the seventy odd research problems in metallurgy with which we are occupied. They may be found in summary form from year to year in the annual reports of the Director and appear in detail as they are completed in the publications of the Bureau and the scientific press. I may mention however some of the broad lines along which we are orienting our work and in doing so will endeavour to emphasize the co-operative aspects of this research work, for much of it is undertaken after consultation or in active participation with other groups having also an interest or a part in its accomplishment.

This co-operation in research takes several forms and is of various types; thus there may be one or more of the other departments of the government interested in the prosecution of a research in which we also have an interest. For example, there has been carried out an investigation of considerable magnitude on the development and properties of

a series of special steels with a view to their serviceability for light armour; in this research the Bureau of Mines, Standards and Navy Ordnance have participated. Again, in consultation with the Advisory Committee for Aeronautics a series of researches on light aluminum alloys has been carried out. For the Army Ordnance, and sometimes in co-operation with that establishment, a whole series of investigations has been executed or are still under way. The list of interdepartmental co-operative researches in metallurgy is of quite considerable length, but the above illustration may suffice to show that to secure scientific co-ordination among the government departments a central body is not indispensible.

Turning now to our co-operative relations with non-governmental bodies, our relations with some of the scientific and technical societies are very close. Thus the work of the American Society for Testing Materials is largely participated in by the Bureau and particularly in Metallurgy our work has often been oriented to meet the desires of the various technical committees which are planning important lines of research of interest to science and industry; for example, coated metals, corrosion of iron and steel, the standardization of ladle test ingots in steel making.

For several years past, the investigations in non-ferrous metallurgy have been largely carried out after consultation with an informal, advisory committee made up of technical leaders in the industry who are also representatives of the several interested scientific and technical societies. This committee meets twice a year at the Bureau and its advice has been most stimulating and gives us in addition a feeling of security that what we are doing is along the lines appreciated by those who will profit most immediately.

With the National Research Council and its several committees on metallurgical matters we are in most active co-operation; I need but mention the work of the Pyrometer Committee and the extraordinarily successful symposium on pyrometry held at the meeting last fall of the American Institute of Mining and Metallurgical Engineers.

There is still another type of co-operation that should be mentioned, namely the solving in the government laboratory of some of the problems fundamental to manufacturing processes and standards which are of interest to an industry as a whole. The development of this type of co-operative industrial research is still in its infancy in the United States, and evidently requires an experimental manufacturing plant for each type of industry. We have made some provision for this field of development in metallurgy by installing several operating or semi-manufacturing units which, on a quarter ton basis, will allow us to make any metal or

alloy, submit it to various heat treatments, shape and work it by rolling, forging, or drawing.

A beginning has been made in manufacturing metal specialities, which are difficult to get elsewhere, for the government. These include instrument castings of various non-ferrous alloys, the nickel-steel of very low expansion known as invar, and experimental light armour plate.

I should like, before closing, to call your attention to a co-operative research of the greatest economic importance, conceived on a somewhat more comprehensive scale than anything else we have hitherto undertaken; I refer to the investigation just gotten under way under the auspices of a Joint Committee to study the effects of sulphur and phosphorus in steel for the purpose of defining the permissable limits of these elements in the specifications for the various grades of steel. This is a subject about which there is a great deal of diverse opinion and the experimental results published thus far have not been considered of sufficient weight to justify changing the present and long accepted values of sulphur and phosphorous contents in steel by responsible specification making bodies.

The Joint Committee, the Chairmanship of which is held by the Bureau of Standards is constituted with representatives of the government including the Departments of Commerce, War and Navy, steel makers, and specification making bodies including the American Society for Testing Materials, the railroads, the automotive and shipping industries. It is hoped, in view of the fact that the programme of tests is mapped out by unanimous agreement of all interested parties; the steel manufacture witnessed by representatives of all interests; and the tests carried out in government laboratories, that the results of this elaborate research will be determinative as to revision of the specifications in question.

With this summary review of a few of the aspects of governmental research, as I see them, and as illustrated specifically in the work in Metallurgy at the Bureau of Standards, I trust you will carry away the impression, which I have endeavoured to convey, that there is a human side to research and that in the government service it is possible to be very close to the public, in fact a part of the public and not a group set apart to solve abstruse problems of little general interest. I believe it not only desirable but absolutely essential that a government laboratory, and by that term I mean the men who work in it, keep in closest possible touch with the professional as well as the non-technical public it serves and that a crucial test of the usefulness of such a laboratory is the interest and above all the confidence it inspires.

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Washington, D.C.

A NEW SPECIES OF *SPIRONTOCARIS* WITH NOTES ON OTHER SPECIES FROM THE ATLANTIC COAST.

By A. H. Leim, B.A.,
University of Toronto.

A study of the group of shrimps contained in this genus has been undertaken to determine the systematic relationships of the species, and it has seemed desirable to publish, as a preliminary report, a description of one new species together with some notes on other Atlantic species. These notes are in part records of hitherto unpublished variations and in part an extension of published ones.

I wish to express my indebtedness to Prof. A. G. Huntsman not only for an introduction to the subject and the provision of the major portion of the material, but also for much direction and assistance.

Spirontocaris zebra, sp. nov., Pl. II, figs. 1-4; Pl. III, fig. 5-9.

Rostrum rather short reaching the distal end of the first protopodite of the antennule in three of the specimens examined, and to the middle of the first protopodite in the other two. In three cases there are three dorsal rostral spines and in the other two there are two dorsal spines. In all five specimens there is only one ventral spine. The rostrum ends anteriorly in a spine which points slightly downward. The anterior rostral spine is smaller than the others and is somewhat closer to the second dorsal spine than it is to the anterior extremity of the rostrum. In the specimens where there are three dorsal spines the posterior two are equal in size and their distance apart equals the distance from the anterior extremity of the rostrum to the second dorsal rostral spine. The ventral spine is on the ventro-anterior edge of the rostrum and it equals the posterior dorsal spines in size and is situated just anterior and ventral to the first or anterior dorsal spine. Just ventral to the tip of the second dorsal spine there is a slight angle in the ventral surface of the rostrum due to the axis of the anterior part of the rostrum rotating downward from the horizontal. The orbit is slightly behind the posterior dorsal rostral spine. The dorsal surface of the carapace is highest about one-third its length from the anterior end or at the point where the second dorsal spine of the carapace is situated. It is about equal in size to the second dorsal rostral spine and points forward. Halfway between

this second dorsal carapace spine and the posterior rostral spine is the first carapace spine, which is hooklike and more slender than the second.

Directly ventral to the first carapace spine is the base of the supraorbital spine. Seen laterally this spine appears wide at the posterior end where it is one-half the depth of the rostrum at the orbit. It is cut off anteriorly in such a way as to end in a sharp spine but the dorsal edge is straight. Seen from above the supraorbital spine is needle shaped, just reaching to the posterior part of the base of the posterior carapace spine.

Suborbital spine strong, pointed, base just ventral to anterior end of supraorbital spine, and its anterior end ventral to the anterior end of the third dorsal rostral spine. At the ventro-anterior angle of the carapace is a sharp stout pterygostomial spine which points slightly downward. It is directly ventral to the suborbital and at a distance from it equal to that between the suborbital and the dorsal side of the rostrum. Pterygostomial spine smaller than suborbital. Carapace convex between them.

Passing posteriorly from the pterygostomial spine the depth of the carapace increases till at the level of the second dorsal carapace spine it is 0.6 of the length of the carapace. Posteriorly the ventral border rises slowly while the dorsal edge falls. In the posterior one-fifth of the carapace the dorsal surface rises, then suddenly falls producing a rounded flange at the dorso-posterior end of the carapace. Posterior to this the dorsal and ventral edges meet in a rounded portion of the carapace which is overlapped by the first abdominal segment.

The first abdominal segment has the ventral edge well rounded, and is wider at the dorsal than at the ventral border, and is overlapped ventrally by the second segment. There are a few setae on the ventral edges of all the segments. The second segment overlaps the first and third and its ventral expansion is almost circular and without a spine. The ventral edge of the third segment is rounded; this segment is very large; its posterior border is almost regularly concave and meets the dorsal convex (in posterior part), overhanging the fourth segment. The fourth segment is not so deep as the third; its posterior border slopes first anteriorly (straight) and then posteriorly (rounded) so producing a ventro-posterior wing that ends in a spine which lies along the ventral edge of the fifth segment. The fifth segment is much like the fourth in shape, but is smaller with a ventro-posterior wing and spine. The sixth segment is stout and short, its dorsal border is straight; at the posterior end is a well developed lateral spine. The dorsal border is longer than the ventral due to a concavity of the ventro-posterior edge producing a dorso-posterior wing ending in a small spine.

The telson is 0.18 of the length of the specimen. It bears six terminal spines, the outer pair (one on each side) are short and stout, the intermediate pair are four times as long as the outers and the median pair do not reach quite to the distal end of the intermediates. On the dorso-lateral surface of the telson there are in three specimens four and in the other two five pairs of stout equidistant spines. The dorsal surface has many long setae scattered over it.

The squame of the antenna extends to the middle of the large flagellum of the antennule and is widest at about its middle. The end of the squame is rounded and serrate. Its inner border bears long setae. The spine of the squame is stout and straight and reaches just to the distal end of the squame. The first endopodite is large, its end being triangular with its point in the middle of the second endopodite. The distal end of the second endopodite is also triangular and its medial side bears setae. The third endopodite is stout and bears many distal setae. Distal end of exopodite bears one long anteriorly pointing spine. Flagellum about 30 mm. long.

First protopodite of antennule split down two-thirds of its length, the lateral spine so formed reaching the distal end of the second protopodite ending in a long tapering spine that points slightly laterally. The main portion of the protopodite bears at its distal end four (two specimens) or three (three specimens) heavy spines. These spines reach the middle of the second protopodite, the most lateral one is needle shaped, the next is like an equilateral triangle, and the remainder are needle shaped. The second protopodite is stout, its disto-lateral spine is sharp and points somewhat laterally reaching the middle of the third protopodite. The third protopodite consists of two triangular pieces overlapping, the median one being more sharply pointed than the other. The flagellum consists of about twenty segments, and narrows gradually to the end, bearing on its medial surface many long setae. The small flagellum is about five mm. long.

The mandible has two prominent cusps separated by a deep groove. The medial one shows slight indentations; palpus is stout, narrowing toward end with external side longest. Teeth are very small. Exopod is two jointed, second joint is rounded and bears setae; it is a little shorter than the palp.

Eye reaches distal quarter of rostrum, fascetted part almost globular, stalk longer than broad.

Exopod of first maxilla bears two spines, outer one small, and the other stout. Sides of endopodite almost parallel giving a squarish appearance not seen in other species. Medio-distal end bears three to four rows of spines, disto-lateral edge and rest of medial with long plumose setae.

Second maxilla much the same as in *S. fabricii*, the protopodites being somewhat higher and the exopodite more slender with the anterior end somewhat rounded.

First and second maxillipedes like those in *S. fabricii*.

Third maxillipede bears small hooked epipodite but no exopodite. The first segment is about equal to the third in length; it is slightly hollowed out laterally at the proximal end. The second segment is one-quarter the length of the third and bears a distal ring of setae. Distally the third segment has, in two specimens ten spines, in one nine spines, and in another nine spines on the left maxillipede and eight on the right. Of these spines the proximal two are small. There are about ten circles of setae on the third segment. The length is about 11 mm.

The first pereiopod has an epidodite. End is chelate. Dactyl cleft at end and one-quarter length of merus; bears distal groups of setae. Propodus stout and three-quarters of the length of the merus; bears scattered setae. Carpus two-fifths length of merus and with setae on a Y-shaped area on lateral side. Merus stout, proximo-laterally bears five strong setae. Ischium, basis, and coxa each one-third length of merus. Length 10 mm.

Second pereiopod with an epipodite, chelate, with dactyl one-sixth length of merus and having a terminal group of setae, with propodus stout and two-fifths length of merus. Carpus slender, seven jointed; third joint longest, equaling first and second together; first, second, fourth and seventh equal; and the fifth and sixth shorter than these. Merus slender, with few setae. Ischium slender, one and one-quarter times the length of the merus, bearing five proximo-lateral spines. Basis one-ninth length of merus. Coxa one-quarter length of merus. Length 13 mm.

Third pereiopod bears an epipodite. Dactyl stout, curved, one-fifth the length of the merus, bears six (three specimens) or five (two specimens) spines which increase in size distally. Propodus one and one-quarter times length of merus; bears about seventeen pairs of spines, the distal ones being the largest. Carpus one-third length of merus; distal lobe which projects over propodus well developed; Merus stout; bears five spines (three specimens) or four (two specimens) on the distal half, the distal one being the largest and the proximal one the smallest. Ischium is stout, one-third length of merus. Coxa one-twelfth length merus; posterior end deeply indented. Basis one-eighth of length of merus. Length 15 mm.

Fourth pereiopod much the same as the third but lacks epipodite. Propodus with twelve pairs of spines. Merus with two spines in two specimens, five in two others and six in the remaining one. Length 15 mm.

Fifth pereiopod much like the fourth also without epipodite. Propodus with seven pairs of spines. Merus with one spine in four specimens, and two in the other. Length 12 mm.

First pleopod (female) with stout protopodite; exopodite slender but not blunt; endopodite two-thirds length of exopodite, stout, tapering from distal third to a point. Length 3 mm.

Remaining pleopods like those of *S. fabricii*. Lengths of pleopods two to five are five, five, four and one-half, and three mm.

Protopodite of uropod with one very blunt spine on the long outer lobe; no inner lobe. Two latero-posterior spines on the exopodite, one behind the other, the anterior being the smaller.

Colour.—In general the body is banded by bright brownish red to orange stripes which run dorso-ventrally. Those of the cephalothorax and the three anterior abdominal segments run somewhat obliquely, the ventral end being the more anterior. On the cephalothorax the areas between these stripes have a bluish tinge; on the rest of the body these areas are whitish. The appendages have alternating bands of white and orange; the bands on the coxa, basis and ischium of the pereiopods are purplish. The edges of all the abdominal segments, except the anterior edge of the second, the lateral edge of the antennal squame, the anterior lateral edge of the first protopodite of the antenna, and the edges of the lateral spine of the first protopodite of the antennule are defined by a sharp red line. The flagellum of the antenna is all red. Ventrally on the cephalothorax are two horizontal orange bands.

Very similar to *Spirontocaris washingtoniana* Rathbun (Rathbun 1902, page 895. Rathbun 1910, page 76) and to *S. profunda* Rathbun (Rathbun 1906, page 914). The rostrum is almost identical with that of the latter, but differs from *S. profunda* in having shorter third maxillipedes, reaching only to the distal end of the squame of the antenna; in having a longer lateral spine (basal scale) on the first protopodite of the antennule; and in having the second pereiopod with a seven jointed carpus. It differs from *S. washingtoniana* in that the rostrum is shorter, and with only one tooth on the ventral edge; in having a longer lateral spine on the first protopodite of the antennule; and in having shorter third maxillipedes.

Dimensions.—All were females and the lengths were 49, 41, 38, 37 and 32 millimetres.

Distribution.—New Brunswick; one specimen from Passamaquoddy bay (48 mm.) at 30 metres: one from Joe's point, St. Croix river (41 mm.): two from Head Harbour, Campobello island, the 37 mm. specimen from 10 metres of water and the 32 mm. one from kelp at low tide. Nova Scotia; one from St. Mary's bay (38 mm.).

SPIRONTOCARIS FABRICII (Kröyer). Pl. IV, fig. 10.

Colour.—Spotted over a whitish ground, the spots being a very deep bright red. There is one exception to this, namely on the basis and coxa of the third to fifth pereiopods where the colour is purple. An area of very fine red dots on either side of the posterior dorsal carapace spines and mixed with these larger spots. Larger scattered spots ventrally and also posteriorly on the cephalothorax. Small dots just posterior to the orbit. Anterior end of rostrum spotted. Also antennae and antennules—the antennal flagellum with five red bands near its end and the edge of each antennal joint with a faint red line. Abdominal segments with scattered spots and on the third segment an area with small dots postero-ventrally. Basal joint of the third maxillipede entirely red, penultimate segment with a few dots, and the terminal segment with two equidistant red rings. Merus of first pereiopod with one red ring, and of the remaining pereiopods with two; propodus of pereiopods three to five with one ring. Protopodite of gonopod with one band of red, and of the remaining pleopods with four spots.

Variations.—An examination of one hundred and forty-eight individuals did not reveal the presence of an epipodite on the second pereiopod in any case. The first pereiopod always had an epipodite. The following table gives the variations in the number of spines on the various parts. The figures indicate numbers of individuals.

No. spines	1	2	3	4	5	6	7	8	9
Dorsal carapace	1	81	84						
Dorsal rostrum	75	82	1						
Ventral rostrum	1	25	114	14	2				
Lateral telson			2	43	43	2			
Merus third pereiopod			1	4	21	22	12	2	1
Merus fourth pereiopod		5	18	28	10				
Merus fifth pereiopod	19	30	14	2					

In all cases but one there were six terminal spines on the telson, in this one case there were nine.

Dimensions.—The males vary in length from 36 to 19 mm., the females from 53 to 22 mm.

Distribution.—New Brunswick; Joe's point, St. Croix river: Head Harbour, Campobello island: Passamaquoddy bay, 'Prince' Sta. 4: Bay of Fundy, 'Prince' Sta. 5. Newfoundland; Bay of Islands, C.G.S. '33' Stations 55 and 56. Maine; Eastport.

Spirontocaris gaimardii (Milne-Edwards).

Variations.—Eight specimens were examined and the following variations in the number of spines found.

No. spines	2	3	4	5	6
Dorsal carapace	4	3	1		
Dorsal rostrum		5	3		
Ventral rostrum		4	4		
Lateral telson (2 broken)			1	4	1

Dimensions.—The females varied in length from 56 to 17 mm., and the males from 39 to 15 mm.

Distribution.—Newfoundland; Port au Port, C.G.S. "33" Sta. 65. Nova Scotia; Brier island.

Spirontocaris polaris (Sabine). Pl. V, fig. 12.

Colour.—Scattered orange red areas over the cephalothorax and abdomen, the colour being due to closely placed minute dots. The major portion of the colouration is on the dorsal surface. Postero-ventrally to the posterior dorsal carapace spine the colour is due to much larger spots. Ventral to these larger spots are several small areas of small dots which have a sulphur yellow tinge. Rostrum with scattered orange spots and its ventral edge bright red. Antennules, antennae, third maxillipedes, and first and second pereiopods with a few scattered spots. Pereiopods three to five with orange band on coxa and basis, two bands on merus, and two on propodus. Protopodite of pleopods two to five with two to three spots, the postero-distal one of which is the largest, and which in pleopods three to five is of a very dark orange colour. The posterior border of the fifth and sixth abdominal segments is defined by a bright red line.

Variations.—There is considerable variation in the numbers of spines on the various parts as is shown in the following table. The figures indicate numbers of individuals.

No. spines	1	2	3	4	5	6	7	8	9	10
Dorsal carapace		20	2							
Dorsal rostrum		6	8	4	3					
Ventral rostrum	1	9	5	3	3					
Lateral telson				8	3	4	3	1		
Merus third pereiopod					2	6	6	3	5	1
Merus fourth pereiopod	1			3	6	4	3	2	2	
Merus fifth pereiopod	9	3	3	3	1		1			

The number of terminal spines on the telson is subject to some variation being usually six or eight but occasionally five.

Dimensions.—Females vary in length from 58 to 21 mm., and males from 49 to 9 mm.

Distribution.—New Brunswick; Bay of Fundy, 'Prince' Sta. 5 and Sta. 120: Grand Harbour, Grand Manan: Green Islands, Grand Manan.

SPIRONTOCARIS GROENLANDICA (Fabricius, J. C.). Pl. IV, fig. 11.

Colour.—Both the shade of colour and the pattern vary much in this species. The colour is usually a brownish red but may show all stages between this and a dull brownish green. The greater part of the animal is coloured. On the cephalothorax there are usually the following non-coloured portions—a small area just posterior to the eye, one dorsal to the pterygostomial spine, one running ventrally from the second dorsal carapace spine, one just posterior to the fourth dorsal spine and several scattered smaller areas, which with the exception of five along the posterior half of the ventral edge vary considerably in position. On the abdomen the principal non-coloured areas are—one running across the first segment on its dorso-lateral surface, several scattered ones on the second segment, one on the dorsal surface of the third segment at its anterior end, one on the dorsal surface of the fourth segment, a narrow band running across the fifth segment which is continued into the sixth for a short distance and which is continuous with that of the fourth segment anteriorly. The ventral edges of the abdominal segments are red. The rostrum, antennules and antennae with scattered dots of colour; the flagella of the antennules and antennae with bands of colour, these not being complete in the case of the larger flagellum of the antennule. Terminal joint of the third maxillipede with two coloured bands, the penultimate with two and the basal joint with one at its distal end. First and second pereiopods with several bands; third to fifth with two bands on merus and propodus and one on carpus and dactyl as well as some colouring on the basal joints. The proximal half of the lateral surface of the protopodites of the pleopods coloured.

Variations.—The rostrum varies considerably, in some being very stout and in others rather slender; the latter condition obtains in the case of the males to a greater extent than in the females. In the males, too, the abdominal segments are not as wide compared to their dorso-ventral length as they are in the females.

The following table gives the variations in the number of spines. The figures indicate numbers of individuals.

No. spines	0	1	2	3	4	5	6	7	8	9
Dorsal rostrum	1	3	26	15	2					
Ventral rostrum		2	16	22	7					
Lateral telson						6	21	12	1	
Merus third pereiopod				4	1	3	14	21	3	
Merus fourth pereiopod			1	2	3	6	17	10	2	1
Merus fifth pereiopod		4	5	9	9	11	4	1		

The number of spines on the ventral edges of the abdominal segments varies much; usually there are two on the first, third, fourth and fifth segments, and one on the second and sixth; in about 25% there is only one on the third, in about 5% the fourth also has but one spine, and two specimens were examined where the fifth had only one spine. On the other hand there may be an increase in the number of spines as the fourth and fifth segments sometimes have three spines and in one case the second had two spines on one side but only one on the other.

Dimensions.—The females varied in length from 65 to 24 mm., and the males from 48 to 29 mm.

Distribution.—New Brunswick; Bay of Fundy, 'Prince' Sta. 5: Head Harbour, Campobello island: Grand Harbour, Grand Manan.

Spirontocaris spina (Sowerby).

Variations.—There is much variation in the form and number of teeth on the rostrum. The rostrum may be concave at its anterior end or pointed depending on the length of the ventral spines. The number of dorsal spines varied from 9 to 33, with an average at 18 to 20. The number of ventral spines varies from 2 to 5. There is a great deal of variation in the size of the dorsal spines especially. There are usually four dorsal carapace spines but occasionally there are five or six.

The telson usually has four, but sometimes five, lateral spines. The spines on the meri are as follows, the figures indicating numbers of individuals.

No. spines	1	2	3	4	5	6	7
Merus third pereiopod				3	2		1
Merus fourth pereiopod			1	3	2		
Merus fifth pereiopod	3	2	1				

The dactyls of the third to fifth pereiopods show considerable diversity of form. They tend to be rather longer and more slender than is typically the case in *Spirontocaris* and the longer they are the weaker

the spines become. In one specimen the dactyls were almost as long as in *S. macilenta*, but were much stouter than they are in that species; in this case the spines had almost disappeared.

Dimensions.—Females varied in length from 59 to 31 mm., and but a single male 27 mm. long was examined.

Distribution.—New Brunswick; Bay of Fundy, 'Prince' Sta. 5: Passamaquoddy bay, 'Prince' Sta. 4. Maine; Eastport.

SPIRONTOCARIS MACILENTA (Kröyer).

Variations.—The variations in the number of spines is given in the following table, the figures indicating numbers of individuals.

No. Spines	0	1	2	3	4	5	6	7
Dorsal carapace	4	5	16	8				
Ventral rostrum		8	11	7	6			
Lateral telson				33	2			
Merus third pereiopod				3	4	13	2	
Merus fourth pereiopod				1	3	16	5	
Merus fifth pereiopod	1		2	2	4	9	7	1

For the dorsal spines of the rostrum the numbers are as follows—

No. Spines	11	12	13	14	15	16
No. specimens	2	4	8	9	8	3

The dactyls of the third to fifth pereiopods are long and usually devoid of spines but in many cases one or sometimes two very small spines were observed near the base of the dactyl.

Dimensions.—The females varied in length from 68 to 38 mm., and the males from 54 to 45 mm.

Distribution.—Newfoundland; Bay of Islands, C.G.S. "33" Stations 57 and 56a.

SPIRONTOCARIS PHIPPSI (Kröyer). Pl. VI, fig. 13.

Colour.—Rather large brownish red spots distributed generally over the whole body and its appendages. The background is not so white as it is in *S. fabricii*, having a more yellowish tinge. Spots more closely packed on the upper half and on the anterior and posterior ends of the cephalothorax than on the rest of it. Also grouped on the dorso-posterior border of the third abdominal segment and on the uropods.

Rostrum, antennules, antennae, third maxillipedes and first and second pairs of pereiopods evenly sprinkled with colour; pereiopods three to five with a group of spots on the coxa and basis, one on the ischium, two on the merus, two or three spots on the carpus and one group on the propodus. Protopodites of the pleopods with from four to six groups of spots and a few on the exopodites.

Variations.—The normal number of supraorbital spines is two, but in a 19 mm. male specimen only one, with no trace of a second, was found. The variations in the number of spines are as follows:

No. spines	1	2	3	4	5	6	7	8	9
Dorsal carapace	1		4	1					
Dorsal rostrum						2		3	1
Ventral rostrum		1	2	4					
Lateral telson				7					
Merus third pereiopod		1	1	3					
Merus fourth pereiopod		3		2					
Merus fifth pereiopod	3	2							

Dimensions.—Females range in length from 25 to 18 mm., only one male was examined, it being 19 mm. in length.

Distribution.—New Brunswick; Head Harbour, Campobello island: Green Islands, Grand Manan: Station 113, Grand Manan.

Spirontocaris pusiola (Kröyer). Pl. VI, fig. 14.

Colour.—Only a few deep red to orange red spots scattered over a whitish background. They are evenly spread over the cephalothorax and the first two abdominal segments. The third abdominal segment with five or six scattered spots; and the fourth to sixth segments with only two or three spots on their postero-ventral surface, the postero-ventral edges of these segments being defined by a sharp red line.

Rostrum without colour. A few spots scattered on antennules and antennae; edges of the segments of the small flagellum of the former red; lateral edges of squame of antenna red, as are the edges of the joints of the antennal flagellum. Third maxillipedes and second and third pereiopods with scattered spots. Third to fifth pereiopods with spots on coxa and basis, three or four in two groups on the merus, one on the carpus, and one group on the propodus. Protopodite of pleopods with one to four spots. Protopodite of uropod with one. Edges of uropods red.

Variations.—There are the following variations in the number of spines:

No. spines	0	1	2	3	4	5
Dorsal carapace		13	8	1		
Dorsal rostrum		9	13			
Ventral rostrum	21		1			
Lateral telson					9	1
Merus third pereiopod		3				
Merus fourth pereiopod	1	2				
Merus fifth pereiopod		2				

Dimensions.—The females varied in length from 28 to 11 mm., and the males from 18 to 12 mm.

Distribution.—New Brunswick; St. Andrews: Head Harbour, Campobello island. Maine; Eastport.

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13. *Spirontocaris phippsi.* Lateral view of female specimen 19 mm. long showing colour pattern.
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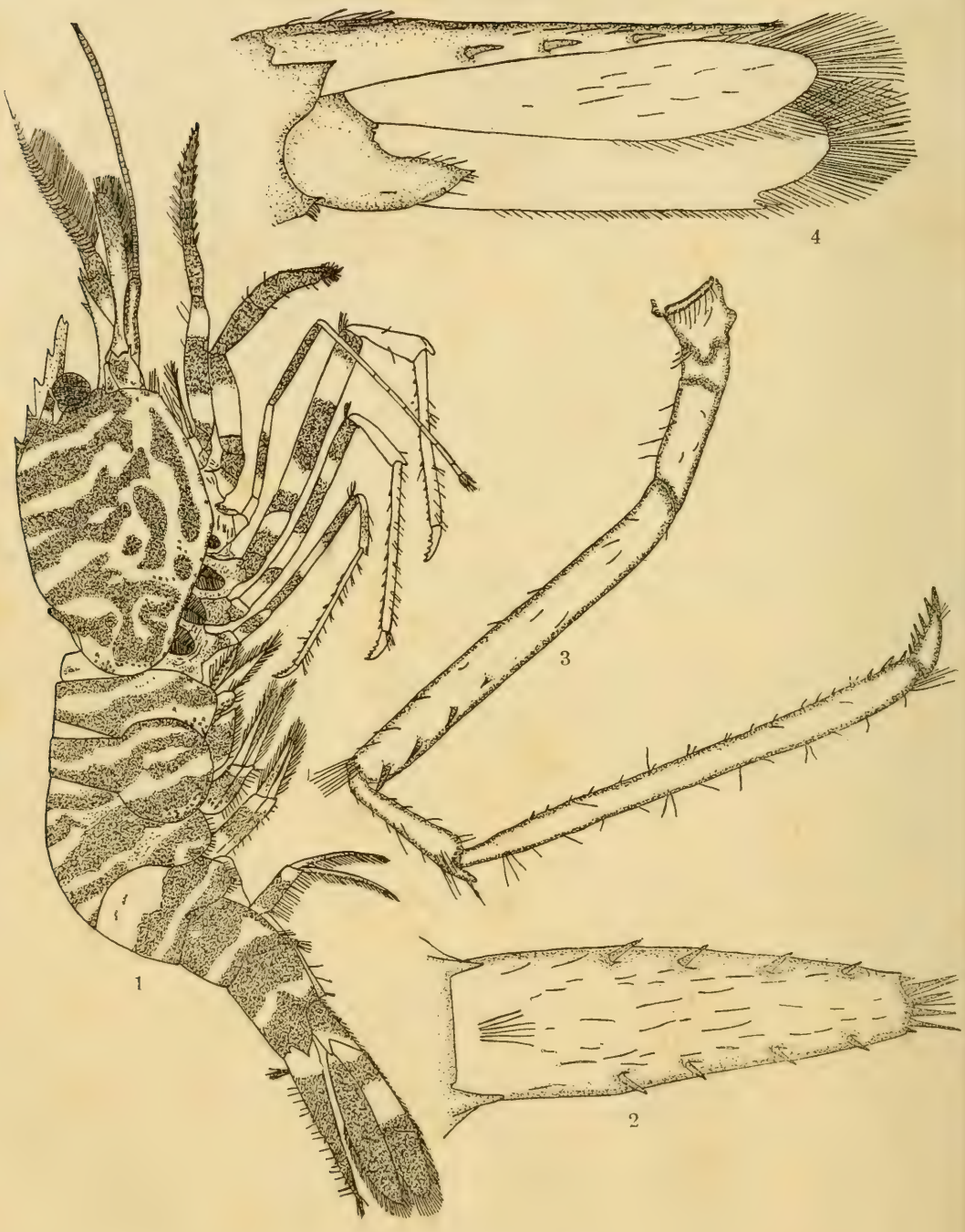

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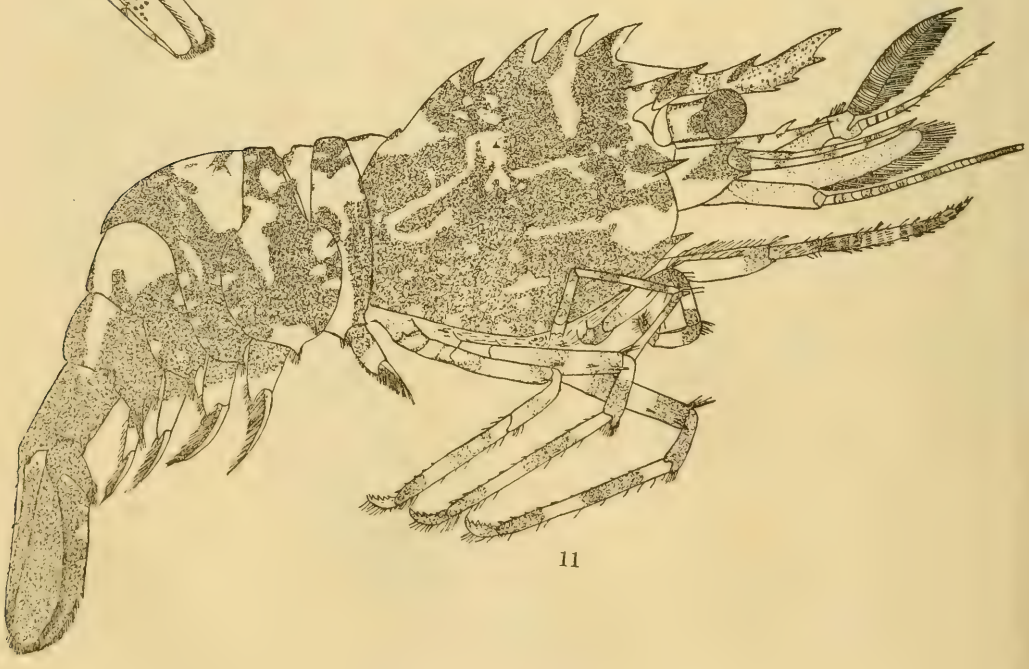

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NUDIBRANCHIATE MOLLUSCA FROM THE VANCOUVER ISLAND REGION.

By Chas. H. O'Donoghue, D.Sc., F.Z.S.

Professor of Zoology, University of Manitoba.

The marine fauna of the coasts of British Columbia is particularly rich and varied and yet, so far, no description of the Nudibranchiata of this region has been published. Indeed this group of animals has only received comparatively little attention on the Pacific coasts of North America in general. One result of this is, that the number of species recorded is not so large as from the western coasts of Europe and this is probably due to a lack of workers and not to a lack of material. It seems advisable therefore to provide a diagnosis of the species so far collected in sufficient detail to render their recognition easy and certain. This will serve as a basis and indeed as a necessary preliminary for future work on distributional, bionomic or developmental lines. It is rather fuller than is necessary in some groups of animals since Nudibranchs appear to be subject to a wide range of individual variation in the matter of size, colour, etc., and practically none possess definite, easily recognisable characters that enable them to be distinguished from allied species. The following list cannot claim to be complete, but it is hoped that at any rate it includes all the commoner forms to be found within the area available from the Dominion Biological Station, Nanaimo, Vancouver Island, British Columbia.

The pioneer work on the Californian coast was done by Cooper (5), Fewkes (8) and Stearns (13), but in all cases their descriptions are indefinite and in some instances so much so that it renders the recognition of the species a matter of difficulty if not impossibility. Bergh (2 and 3) in 1879, 1880 and 1894 described a number of forms not only from the Californian coast but also from Alaska, but unfortunately all of his work was done upon preserved specimens and these are always altered as a result of the preservation. Apart from a note on some Californian species by Cockerell and Eliot (4) the recent work on the same area has been done by MacFarland. This author in a series of papers (10, 11, 12) has described certain genera in a most satisfactory manner. In his work he expresses regret at the lack of adequate coloured drawings of the different species of the Pacific, a gap that he has done much

to fill, owing to the impossibility of preserving either the natural form or colour of these animals. This alteration in appearance is so striking in some cases that the species cannot be recognised without dissection and even then may be uncertain unless the preservation is good. For that very reason a completely satisfactory account of any form necessitates the examination of living specimens; and the establishing of a colour variety such as Bergh has done (3, p. 172) in the case of *Diaulula sandiegensis* var *pallida* on preserved material is a hazardous proceeding and can only be justified by subsequent reference to living material. Indeed, if I may venture to criticize one who is perhaps the foremost authority on this group, Bergh was inclined to make new varieties or even species for forms found on this coast without sufficient grounds for so doing. In certain cases the colour entirely disappears after a few hours and after some time has elapsed specimens taken together and preserved together will have a very different appearance, owing presumably to the different physiological conditions of the individual at the time of fixing.

The colour of living members of the same species is subject to considerable variation and in some instances the colours of specimens collected here differ from those from Monterey described by MacFarland and to this I have called attention when necessary. It is not meant to imply that MacFarland's account is inaccurate, but simply that the specimens obtained here are somewhat different. There is of course a distinct difference in the local environment, for on the whole there is considerably more sand at Monterey Bay than anywhere I have collected. This however does not appear to have any general affect on the nature of the colour difference for while in some species, e.g., *Diaulula sandiegensis* it is considerably darker, in others, e.g., *Cadlina marginata* it is much lighter.

MATERIAL.

The following list is based upon material collected from the Biological Station, Nanaimo, B.C. The preserved material in the station was kindly placed at my disposal by Dr. C. McLean Fraser who had collected most of it, the rest being a few specimens obtained by Professor J. Playfair McMurrich and the late Rev. G. W. Taylor. In adddition I have collected a number of species and examined a large number of individuals while still living, so that unless otherwise stated the descriptions are based upon living material and the preserved specimens have been utilized for data regarding distribution. The living material has enabled me to give colour notes for certain species that have not been available previously. In some cases specimens in spirit or formalin have been the only ones examined and the account of their colour has been taken from

other authorities, but this is duly noted. The pharyngeal complex of each species has been examined, where possible several radulae mounted and in nearly all cases the animal was dissected. All the drawings were made from my own preparations and were made by means of the camera lucida.

The list is practically complete as far as the available material is concerned but one or two forms have been omitted as their preservation is not good and they are better left undescribed until further material renders their identification easier and more certain.

The following species are recorded:

I. HOLOHEPATICA.

Tritonia diomedia.
Tritonia exsulans.
Archidoris montereyensis.
Anisodoris nobilis.
Diaulula sandiegensis.
Cadlina marginata.
Laila cockerelli.
Triopha elioti. sp. nov.
Acanthodoris pilosa var *albescens.*
Acanthodoris hudsoni.
Acanthodoris brunnea.
Acanthodoris nanaimoensis. sp. nov.
Lamellidoris bilamellata.
Idalia vancouverensis. sp. nov.

II. CLADOHEPATICA.

Pleurophyllidia californica.
Dirona albolineata.
Dendronotus arborescens.
Dendronotus dalli.
Dendronotus giganteus. sp. vov.
Dendronotus ruber. sp. nov.
Chioraera leonina.
Coryphella fusca. sp. nov.
Coryphella trilineata. sp. nov.
Aeolidida papillosa.
Doto columbiana. sp. nov.
Hermissenda opalescens.

Type specimens of each have been placed in the museum of the Biological Station at Nanaimo.

I am glad of this opportunity of expressing my thanks to Dr. C. McLean Fraser, Curator of the Pacific Coast Biological Station not only for placing the material at my disposal but also for his unfailing kindness and courtesy to me during my stay.

The question of the classification of this as of any other group of animals is a vexed one and much of it appears to be ultimately a matter of preference. It is not intended therefore to enter into a discussion of that subject here but to adopt the scheme put forward by Eliot in "British Nudibranchiate Mollusca Part VIII" Supplementary 1910. It may be briefly outlined as follows.

The EUTHYNEUROUS GASTROPODA are divided into two orders, the PULMONATA and the OPISTHOBRANCHIATA and the latter again into two sub-orders, the TECTIBRANCHIATA and the NUDIBRANCHIATA. It is with the last sub-order alone that we are concerned here. The NUDI-

BRANCHIATA themselves are split into two tribes, the HOLOHEPATICA and the CLADOHEPATICA. This classification as its terminology implies is based in the main upon the condition of the liver, *i.e.*, as to whether or not it is split up, but this accompanied also, by other anatomical features.

DESCRIPTION OF THE SPECIES.

Tribe I. HOLOHEPATICA.

Nudibranchs in which the liver forms a compact mass, neither branched nor divided. Usually accompanied by the following characters. Almost complete external symmetry; vent usually on the mid dorsal line and surrounded by a circle of branchial plumes; radula of moderate or considerable width and not known to be reduced in any genus; mandibles are rare; hermaphrodite gland not a separate mass but spread over the liver as a layer; as a rule the genital ducts are triaulic and there are two receptacula seminis.

Family TRITONIIDAE.

Branchiae consisting of tufts set along the mantle margin or occasionally altogether absent.

GENUS TRITONIA (Cuv).

Alder and Hancock, Mon. Brit. Nud. Moll., Pt. VII, 1855. p. 46. Proc. Ac. Nat. Sci. Philadelphia, Pt. I, 1879. p. 95. Bergh, Malacol. Untersuch, Vol. III, Heft 15, 1884. Bull. Mus. Comp. Zool., Harvard, Vol. XXV, No. 10, 1894. p. 146. Eliot. Brit. Nud. Moll., Pt. VIII, 1910. p. 145.

"The body is limaciform but somewhat rectangular in outline, except at the end where it tapers to a short tail. The foot is broad. Over the mouth is an oral veil bearing two grooved tentacles at the end, and in the middle tubercles or processes. The rhinophores are retractile into raised sheaths; not perfoliate but surrounded by a few plumes. The dorsal margin is slightly prominent and bears a single row of branchial tufts which are more or less arborescent. Anal and rectal openings on the right side. Jaws large with several rows of denticles or prominences near the edge. The radula varies greatly in size in the different species, but always consists of a broadish central tooth with a moderate or large number of laterals which are usually simply hamate. The first lateral is usually larger and lower than the others and somewhat clumsily shaped. The liver is not divided and sends off no branches to the gills.

There is no armature either in the stomach or on the genitalia. The hermaphrodite gland forms a layer spread over the liver." (Eliot I. c.).

TRITONIA DIOMEDIA Bergh.

Tritonia diomedia Bergh, Bull. Mus. Comp. Zool., Harvard, Vol. XXV. no. 10, 1894. p. 146.

Body.—The body is stout and limaciform ending posteriorly in a blunt tail and is approximately rectangular in cross section. The dorsum is fairly flat and smooth reaching its highest point about half way back. A low pallial ridge along each side of the dorsum separates it off from the sides of the body and along the ridge are placed the branchial tufts, 13-15 in number. The stout rhinophore sheaths lie just in front and inside the anterior gill tuft. The veil is well developed in the form of two lobes with a notch between them and bears on each side 11 small blunt conical papillae and at its postero-lateral edge a fairly broad deeply grooved tentacle.

The anal papilla is short and lies about half way back on the right side of the body below the gill tufts. Just above it is a minute renal pore. The genital aperture is also on the right side further forward and lower down.

Colour.—I have not examined this species alive and so cannot describe its colour. When preserved it is of a whitish colour with indications of brownish pigment on the back and sides. Bergh also examined preserved specimens but hazards the suggestion that "Die Farbe des lebenden Thieres ist warscheinlich roth oder purpurroth gewesen".

Dimensions.—The specimen was only a small one measuring, preserved, 25 mm. long by 10 mm. wide by 8 high, whereas dimensions of the larger of Bergh's specimens was 60 mm. long by 35 mm. wide and 27 mm. high.

Head.—The head is well developed and broad and its corners produced to form the grooved tentacles already noticed as lying at the posterior border of the veil. The mouth is a longitudinal slit with distinct lips.

Foot.—The foot is broad and flat ending behind in a blunt tail. In front it is abruptly rounded and bilabiate, the two lips of approximately equal thickness.

Rhinophores.—The rhinophore is retractile within a short stout cylindrical sheath with a practically smooth edge. The clavus bears a crown of *10* simply pinnate papillae of which the hindermost is the largest.

Branchiae.—The branchiae are in the form of small branched tufts

and alternate in size. The larger ones are directed upwards partly over the back and the smaller ones point laterally and slightly downwards.

Radula.—The radula is strong and broad and bears from 38-42 rows of teeth. Bergh gives the total number as 73. The lateral teeth in the widest part of the tongue number from 58-60 on each side. The median tooth is broad and possesses 3 cusps which are however fairly short. The first lateral teeth are elongated and triangular and quite different in shape from the remainder. The remaining laterals are claw shaped getting longer and more slender as they pass outwards.

Jaws.—The jaws are yellow in the outer parts and a deeper brownish colour along the cutting edge. They are in the form of two curved longish oval plates with the cristae connectivae well developed and joined by a tough connective tissue. The cutting edge is strong and continued back as two fairly long processes which are free from the lateral plate. Over the major portion of its length and along the extensions, the edge is provided with a number of closely fitting polygonal plates many of which bear pointed denticles. The other plates without the denticular points are much smaller and form a sort of smooth pavement. The penis is short and sub-conical.

This species was first described by Bergh (3) from specimens obtained from Shumagin Bay, Alaska, and from off the coast of California. This author gives a good account of the internal anatomy.

Habitat.—The one specimen examined was dredged in 15-25 fathoms in the entrance of the channel between Jesse and Newcastle Islands.

TRITONIA EXSULANS Bergh.

Tritonia exsulans Bergh. Bull. Mus. Comp. Zool., Harvard, Vol. XXV, 1894. p. 150.

Body.—The general body form is a broad oval with a pointed posterior end. The dorsum is fairly flat and irregular; it is highest about the middle and slopes off more sharply behind than in front. Along each side of the dorsum is a low ridge bearing from 16-19 small branched gill tufts and marking it off sharply from the sides which slope rapidly downwards and outwards to the edge of the broad foot. The large rhinophore sheaths lie just antero-median of the first gill tuft. The veil is strongly developed but not projecting far and well notched in the middle line; on each side it bears a series of 12-14 small conical papillae and on the ventral side at the lateral edge a broad, short, grooved tentacle. The short anal papilla lies about half way back on the right side of the body below the line of the branchial tufts. Above it is the renal pore. The genital aperture is situated on the same side as and below the anal papilla not quite half way between it and the level of the rhinophores.

Colour.—When preserved these animals are of an opaque white colour and one had a faint pinkish tinge. Dr. Fraser informs me that when alive the dorsum is of a rose pink colour.

Dimensions.—The largest specimen measured was considerably larger than that examined by Bergh for it measured 84 mm. long by 51 wide by 30 high as against 44 mm. long by 17 broad by 15 high so that when alive it was quite a large animal.

Head.—The head is broad and well marked. The mouth is a longitudinal slit with thickish lips and the latero-dorsal corners of the head continued out as the grooved tentacles that have already been noted as forming the postero-lateral border of the veil.

Foot.—The foot is very broad and flat; posteriorly it terminates in a pointed end while anteriorly it is abruptly rounded and bilabiate, both lips being about equally thick.

Rhinophores.—The clavus of the rhinophore is not perfoliate. The stalk of the clavus is cylindrical and bears at its upper end a crown of from 10-12 feather shaped papillae. These alternate as simple and doubly pinnate structures of which the posterior is bi-pinnate much taller than the rest and terminates in a point so that it is quite unlike that of *T. hombergii* as described by Alder and Hancock. The short sheath is cylindrical and terminates at the upper extremity in a slightly crenulate margin.

Branchiae.—The small branchial tufts numbered from 16-18 on each side and decreased in size and complexity from before backwards and alternate; the larger ones being directed medially and the smaller laterally. The stem of each tuft is broad, somewhat flat and soon dividing into two or three main stems which in their turn split into smaller bi- or tripinnate branches.

Radula.—The radula is large and well developed being slightly longer than broad. It bears from 45-52 rows of teeth. The median teeth are broader than long and tricuspid. The middle cusp is moderately long and pointed while the lateral cusps are not so long and have a point at their inner corner. On each side of the median tooth is a modified lateral tooth somewhat triangular with a bluntly pointed cutting edge at their interior corners. They are followed by a series of lateral teeth varying greatly in numbers reaching a maximum near the middle of from 60-64. Each tooth is fairly thin and claw shaped.

Jaws.—The yellow jaws too are very well developed and occupy practically the whole anterior end of the wide pharynx. The crista connectiva is well developed and the two jaws lightly bound together by tough connective tissue. The cutting border of the mandible, corresponding to the processus mascatorius, is quite long, brown in colour

and continued down as a short pointed process. Its edge bears a series of polygonal plates and a few rows of short tiny papilliform denticles. Altogether it constitutes a most powerful masticatory apparatus. The penis is short and sub-conical.

This species was first described by Bergh (3) from specimens obtained from the coast of Southern California in from 43-48 fathoms, he also gives a satisfactory account of its internal anatomy.

Habitat.—Unfortunately precise data as to the locality and depth from which the two larger specimens examined here were obtained is lacking. They came from somewhere near Departure Bay and were obtained by dredging. Three smaller specimens were dredged by Professor McMurrich on Swiftsure Shoal in 23 fathoms.

Family DORIDIDAE CRYPTOBRANCHIATAE.

Branchiae retractile into permanent pocket. Two spermatothecas.

Genus ARCHIDORIS (Bergh).

Doris, auct.

Archidoris Bergh, Malacologische Untersuchungen (Semper, Reisen im Archipel der Philippinen, II, Bd. III), H. XIV, 1878; p. 616. Supplement-Heft 1, 1880, p. 33; H. XVIII, 1892, p. 1092. Nudibranchiate Gasteropod Mollusca of the North Pacific Ocean, I, Proc. Acad. Nat. Sci. Phila; 1879, p. 106. Report on the Nudibranchiata, Challenger Reports, Zoology, X, 1884, p. 84. System der Nudibranchiaten Gasteropoden, p. 100, 1892. Die Opisthobranchien (Albatross Expedition), Bull. Mus. Comp. Zool., XXV, 1894, 10, p. 157.

Body not hard, subdepressed, notaeum granular or tubercular; tentacles short, thick, with external longitudinal sulcus; branchial plumes not numerous 3-4 pinnate; the foot wide, its anterior margin superficially sulcate. Labial armature none. Rhachis of radula naked, pleurae multidentate, teeth hooked. Penis unarmed. Vagina unarmed.

ARCHIDORIS MONTEREYENSIS (Cooper).

Doris montereyensis Cooper, Proc. Cal. Ac. Sci. II, 1862, p. 204. Proc. Cal. Ac. Sci. III, 1863, p. 158.

Archidoris montereyensis Bergh. Mal Unters, H. XIV, 1878, p. 624. Nudibr. Moll. North Pac. Ocean, Proc. Ac. Nat. Sci. Phila., 1879, p. 107, and Syst. der Nudibr. Gast., 1892, p. 100. MacFarland, Proc. Biol. Soc., Washington, XVIII, Feb. 1905, p. 37. Bull. Bur. Fisheries, Washington, Vol. XXV, 1905, p. 114, pl. XXIII. Cockerell and Eliot, Jour. Malac., Vol. XII, 1905, p. 34.

Body.—The body is a somewhat elongated elipse with the ends about

equally rounded. The dorsum is arched but not markedly so and covered with low bluntly conical tubercles of varying sizes. The mantle is thick and extends well beyond the foot all round save that in active crawling the tail end of the foot may protrude for a short distance.

Colour.—The general ground colour is a dusky yellow and the dorsum is covered with brownish or black patches irregularly arranged. The animal can readily be recognized from the illustration given by MacFarland (Fig. 4, pl. XXIII), but in the specimens I have seen alive, amounting to over 100, the spots have been relatively not so large but more numerous; however they are subject to considerable variation. The colour disappears quickly in spirit or formalin save for the spots which persist some long time.

Dimensions.—The largest specimen examined measured; length 48 mm., breadth 24 mm., height 12 mm.

Head.—The head is small with a small vertical slit like mouth. Its sides bear short, blunt, fold like, auriculate tentacles which are grooved on their postero-external margin.

Foot.—The foot is also eliptical but narrower than the body; it is without a median notch; the anterior margin bilabiate with the upper lip wider and thicker than the lower.

Rhinophores.—The rhinophores are fully retractile into deep sheaths with a tuberculate margin. The clavus is borne upon a slightly conical stalk; it is somewhat dilated, sub-conical, perfoliate having 24-30 leaves on each side.

Branchiae.—The seven branchial plumes are 3-4 pinnate and spreading and can be completely withdrawn into a deep sheath with a tuberculate margin. They are of a dusky yellow or brown colour almost always darker than the body colour and arranged in a broad horseshoe shape around the truncated, conical anal papilla. The renal opening is just anterior to the anal papilla on the right side.

Radula.—The radula is pale, deeply grooved, short and broad. The teeth are arranged in 30-33 rows. The rachis is narrow and naked. The pleural teeth vary from about 42 anteriorly to 50 posteriorly, are strongly hooked and compressed. The largest teeth are near the middle of the row and they decrease in size inwards and more rapidly outwards.

The glans penis is unarmed and when everted conical, long and slender.

This species was first described by Cooper (5) in 1863 and dried specimens were obtained by Bergh (2) from Sitka, Alaska. Cockerel and Eliot (4) describe three small specimens from La Jolla in Southern California. The first full account has been given by MacFarland (10,11) who describes fairly completely the internal anatomy of this form. It

is unnecessary to repeat his excellent description which I have been able to verify in practically all points from my own dissections.

Habitat.—It is fairly common at any rate in April, May and June on the rocks and in tide pools around Departure Bay, Jesse Island, Newcastle Island and Brandon Island and has also been found at False Narrows, Mudge Island and the Lagoon near Hammond Bay. Others were dredged in 25-30 fathoms in Fairway Channel off Gabriola Island (Station 4). As it has also been collected in Alaska and Southern California it is probably generally distributed all along the west coast of North America. Superficially this species resembles the next, *Anisodoris nobilis*, a point that will be dealt with later.

Genus ANISODORIS (Bergh).

Anisodoris Bergh, Die Opisthobranchien der Sammlung Plate, Fauna Chilensis, Heft 3, 1898, p. 508.

Montereina MacFarland, Proc. Biol. Soc., Washington, Vol. XVIII, Feb. 1905, p. 38. Bull. Bur. Fisheries, Washington, Vol. XXV, 1905, p. 116.

So far the species of this genus recorded by Bergh and MacFarland are from Chile and Monterey Bay, that is from the Pacific coast of South America and southern North America. The present record extends the northern limit of the genus.

ANISODORIS NOBILIS (MacFarland).

Montereina nobilis MacFarland. Proc. Biol. Soc., Washington, XVIII, Feb. 1905, p. 38.

Anisodoris nobilis MacFarland, Bull. Bur. Fisheries, Washington, XXV, 1905, p. 116, pl. XXII.

Body.—The plump body is a somewhat elongated elipse with the ends about equally rounded, relatively a little broader than the preceding species. The dorsum is more arched rising more abruptly anteriorly than posteriorly; it is covered with tubercles of various sizes with somewhat dilated ends. The mantle is thick and everywhere extends beyond the level of the foot save that in motion the tail of the foot may protrude a short way.

Colour.—The general ground colour of the whole animal is deep bright yellow or orange yellow with a number of small dark brown or black patches on the back. Again although well over 100 specimens have been seen alive none has quite so many dark pigmented spots on the dorsum as shown in MacFarland's figure (pl. XXII). Two specimens taken from the float at the Station on 10th and one large one on 28th of June, 1919, were of an opaque dead white colour without any trace of yellow colour

or pigment spots. Examination of the radula and internal organs however showed them to be of the same species. Again three specimens obtained from Newcastle Island on 9th, July 1919, were of a dingy chocolate shading off to a dark yellow at the border of the mantle, so that the species exhibits a comparatively wide range of colour variation. The colour of this species lasts much longer in spirit or formalin than does that of the preceding species.

Dimensions.—Most of the specimens measured were of small size, averaging about 70 mm. long by 32 mm. broad by 15 mm. high. The maximum one measured was 172 mm. long by 51 mm. broad by 22 mm. high and this was one of the white specimens although one of the normally coloured ones approached nearly to this size.

Head.—Larger than in *Archidoris montereyensis* with a small mouth not in the form of a definite slit but more rounded. The oral tentacles are digitiform about 4.5 mm. long directed antero-laterally.

Foot.—The foot is eliptical but tapers somewhat behind and is of yellowish colour. Anteriorly it is bilabiate with a suspicion of a notch.

Rhinophores.—The rhinophores can be fully retracted into deep sheaths with tuberculate margins. The stalk is conical and so is the perfoliate clavus which bears about 25 leaves and there is a fairly sharp line of demarkation between them.

Branchiae.—The six branchial plumes are 3-4 pinnate. They are very large and plumose and when fully expanded cover the posterior portion of the dorsum out to its edges. They are arranged in a circle and joined at their bases by a thin membrane and are of a light colour, frequently white but almost invariably lighter than the body. The large sub-conical anal papilla is situated at the centre of the circle and the renal aperture in front of it and to the right and between it and the bases of the two anterior plumes of the right side.

Radula.—The radula is pale, deeply grooved short and broad. The teeth are arranged in 25-27 rows. The pleural teeth are large strongly hooked and on the whole similar to those of *Archidoris montereyensis.* They are about 60 in number in the posterior rows and drop to about 55 at the anterior end and the hooks of the teeth in the middle of the row are much more curved than in *A. montereyensis.*

The glans penis is unarmed and when everted conical and not slender.

This species was first described by MacFarland (10) from Monterey Bay and designated *Montereina* being placed in a new genus: the same author later (11) however referred it to the genus *Anisodoris.* He has furnished a good description of the internal anatomy and I have been able to obtain confirmation of his account by actual dissection of the animals.

Habitat.—It is the commonest Nudibranch in and around Departure Bay being found in the tide pools and on the rocks during April, May, June and July. Specimens have been obtained from Jesse Island, Brandon Island, Newcastle Island, False Narrows, Mudge Island, etc., and it has been dredged also at a number of points. Generally it is to be found in association with the preceding species which it resembles superficially in appearance and is also similar in habits, clinging to the rocks as the tide recedes and remaining exposed to the air for quite long periods in the corners and under ledges where it is not exposed to the direct rays of the sun. The two species may be readily distinguished on a little closer inspection by the following characters all of which however may not be marked in one individual.

ANISODORIS NOBILIS	ARCHIDORIS MONTEREYENSIS.
Arched dorsum.	Flattish dorsum.
Generally bright yellow.	Dingier brownish yellow.
Branchial plumes lighter in colour than the body.	Branchial plumes generally darker in colour than body.
Plumes large and plumose. 6 in number.	Plumes smaller and not so plumose. 7 in number.
Plumes in circle joined at base.	Plumes in almost a horse shoe free at base.
Oral tentacles auriculate flattened and grooved.	Oral tentacles digitiform.
May reach a length of 20 cm.	Maximum size about 50 mm.
Large prostate gland.	No prostate gland.

Genus DIAULULA (Bergh).

Diaulula Bergh, Gattungen nordischer Doriden, Arch. f. Naturgesch, XXXV, 1879, p. 343. On the Nudibranchiate Gasteropod Mollusca of the North Pacific Ocean (Sci. Results of the Explor. of Alaska, I, Art. VI), Proc. Acad. Nat. Sci. Philadelphia, 1880, pp. 40-46. System der Nudibr. Gastero, 1892, p. 105. Die Opisthobranchien, Bulletin Mus. Comp. Zool. Harvard, XXV, 10, 1894, pp. 171-175.

Body fairly soft and depressed; notaeum silky minutely villous; tentacles digitiform; branchial aperture rounded, crenulate, branchiae tripinnate; foot rounded in front, bilabiate, upper lip notched in median line. Labial armature none. Rhachis of tongue naked. Pleurae multidentate, teeth hooked. Penis unarmed, prostrate large.

DIAULULA SANDIEGENSIS (Cooper).

Doris (*Actinocyclus*) *Sandiegensis* Cooper, Proc. Cal. Acad. Nat. Sci. II, 1862, p. 204; III, 1863, p. 58.

Diaulula sandiegensis Bergh, Proc. Acad. Nat. Sci., Phila; 1880, pp. 40-46; MacFarland, Proc. Biol. Soc., Washington, XVIII, Feb. 1905, p. 41; Bull. Bur. Fisheries, Washington, Vol. XXV, 1905, p. 122, pl. XXIII.

Body.—Somewhat flattened, oval with ends equally rounded. Edge of mantle wide, fairly thick, and extends everywhere well beyond the body with a wavy margin. The tip of the foot just shows beyond the mantle when the animal is crawling actively. The whole dorsum is covered with small closely set villi which give it a soft velvety appearance.

Colour.—MacFarland (11, p. 122) says "The general colour of the dorsum may vary from light yellow to deep brownish yellow or even chocolate", and previously describes the dorsum as "pale yellowish in colour with dark brown or black rings of varying size number and position". In the specimens I have seen alive amounting to over 50, in or near Departure Bay the colour in the middle region of the back was of a chocolate or even a dark chocolate colour shading off to a lighter brown towards the edge of the mantle but in none could it be described as light yellow save in very small specimens up to 5 mm. and even then the chocolate colour was apparent on the back. One specimen was of lighter colour than the rest but even then hardly pale yellow. The larger spots, often of irregular shape were arranged on the back somewhere on each side of the middle line but hardly to be regarded as forming even indefinite lines. A few smaller spots occur on the back near the middle line and a larger number around the margin. MacFarland notes that the number of spots is subject to variation and may consist of as few as two rows of three. In the specimens here however it is always considerably more than that and never as few as in the figure given by MacFarland so that this together with the difference in ground colour renders the darker more spotted variety hard to recognize from the plate. The colour is retained in preservation for a longer time than is the case in most nudibranchs and traces of the spots can sometimes be seen for a number of years. The spots themselves, particularly the larger ones, are not quite as indicated in MacFarland. Each consists of a light pale greyish white narrow ring, surrounding a thin black ring and then the interior is filled with a deep chocolate colour considerably darker thaa the body colour.

Dimensions.—MacFarland does not give the measurements of this species but from his figure the length is about 70 mm. and the breadth

27.5 mm. The largest living specimen I have noted was 30 mm. long by 15 broad by 6 high but some preserved specimens must have been larger than this though none appear more than 40 mm. long.

Head.—The head is small, quite hidden by the mantle and bears laterally a pair of digitiform tentacles about 1.5 mm. long. The mouth is a small longitudinal slit.

Foot.—The foot is narrow elongated oval; the front end is sharply rounded off and the hinder end comes to a blunt point. It is bilabiate anteriorly and the thin upper lip has a slight median notch.

Rhinophores.—The rhinophores can be completely withdrawn into a deep sheath with a crenulate edge. They are sub conical with a dilated perfoliate clavus bearing 20-30 leaves.

Branchiae.—The six tripinnate plumes are in nearly a complete circle around the anal papilla and can be entirely withdrawn into a sheath with a slightly crenulate margin. The anal papilla is large while the renal aperture lying in front and to the right of it is small and inconspicuous.

Radula.—The radula is yellow, fairly deeply grooved short and broad. The teeth are arranged in 19-22 rows each half row containing from 25-30 teeth. The rachis is broad and naked. The teeth are flattened and strongly curved; the innermost two or three small, the following ones larger and diminishing again to the edge.

The glans penis is well developed, unarmed but covered with thin cuticle.

A short description of the external features of this species was given by Cooper, later the internal anatomy was dealt with by Bergh in forms from Alaska.

Habitat.—It is fairly common in the neighbourhood of Departure Bay on rocks and in pools during April, May and June. Specimens have been taken from the Lagoon near Hammond Bay, Jesse Island, False Narrows, Mudge Island and dredged in Northumberland Strait (Station 5) and other places. This form has been recorded from various places on the Pacific coast of North America: Sitka, Unalaska, Puget Sound, Monterey Bay, Santa Barbara, San Diego and a light coloured variety (var *pallida*) is recorded by Bergh from Punta Delgada off the coast of Patagonia.

I feel inclined to doubt strongly the validity of this var *pallida* as given by Bergh (3, p. 172). It was founded on three specimens preserved in alcohol, the main difference being that of colour. That author says "Trotz dem Fehlen der bei anderen Individuen gesehenden dunkeln Ringen stelle ich, vorlaufig wenigstens, diese Form als eine helle Varietät der *Diaulula Sandiegensis* hin". The preservation of the colour of most nudibranchs is subject to great variation dependent among other things apparently, upon the preservative used, its strength, amount of subse-

quent exposure to light and the state of the animal when killed. This is true of *D. sandiegensis* for while I have examined a specimen preserved in April 1912 in which the colours have remained as in the living form, others collected in 1915 are white and like Bergh's specimens without a trace of the spots showing, yet when they were taken they were normally coloured.

Genus CADLINA (Bergh).

Cadlina Bergh, Proc. Phila. Acad. Nat. Sci., 1879, p. 114; Bull. Mus. Comp. Zool., Harvard, XXV, p. 168. System der Nudibr, Gasteropoden, 1892, p. 108; Malacol, Unters, XVIII, 1892, p. 100.

Dorsal surface as a rule granulate or bearing small tubercles. Rhinophores short, broad and flat. Foot broad. Labial cuticle armed with a plate or band composed of minute hooks. The rachis of the radula bears a median denticulate tooth; the lateral teeth are hamate and denticulate. In most species (but not in *C. clarae*) the verge is armed with rows of minute hooks. Glans penis armed with a series of hooks.

CADLINA MARGINATA (MacFarland).

Cadlina marginata MacFarland, Proc. Biol. Soc., Washington, XVIII, 1905, p. 43; Bull. Bur. Fisheries, Washington, 1905, p. 125, pl. XXV; Cockerell and Eliot, Jour. Malac., XII, 1905, p. 35.

Body.—The body is somewhat flattened and elliptical being slightly more pointed posteriorly. The dorsum is firm and covered with low tubercles fairly regularly arranged. The mantle is thick and wide, extending well beyond the body all round save that the hinder end of the foot may project posteriorly during locomotion.

Colour.—MacFarland (p. 125) describes the ground colour as "everywhere clear translucent yellowish white" and depicts it on pl. XXV as of quite a deep yellow. All the living specimens I have examined in this region are of a clear translucent white with no trace of yellow. The tips of all the tubercles, the rhinophores and the branchial plumes are of a beautiful pale yellow colour. The characteristic marking from which the species is named is a narrow band of the same pale lemon colour which runs round the entire margin of the mantle and also around the edge of the foot save across the anterior border. In several of the specimens also there was a series of small pale yellow spots along the side, in the substance of the mantle in one case nine in number and in another five on each side. In spite of this there is no doubt from the

other features, the radula and internal organs, etc., that they were simply varieties. The colour disappears very rapidly in alcohol or formalin so that in a day or two no trace of it remains. The plumes in all cases were white and only tipped with pale yellow. One perfectly white specimen was obtained and in this also after preservation the yellow spots in the substance of the mantle showed by transmitted light although not clearly visible externally. Its radula and internal anatomy showed it to be a typical *C. marginata.*

Dimensions.—The largest specimen measured in the living condition was 33 mm. long, 17 mm. broad, and 6 mm. wide.

Head.—The head is small with a longitudinal slit-like mouth The short flattened triangular tentacles bear a groove on their postero-external border.

Foot.—The foot is quite narrow and elongated and as noted before has a pale yellow line around the margin save in front. Anteriorly it is abruptly rounded and divided into two lips, the lower thick and the upper thin and bearing a median notch.

Rhinophores.—The rhinophores incline backwards and are completely retractile into a shallow sheath with a tuberculate margin. The stalk is short and the perfoliate clavus subconical, bearing 16-18 leaves.

Branchiae.—The six bi-pinnate branchial plumes are arranged in an almost complete circle and are retractile into a shallow sheath with a tuberculate margin The anal papilla completes the gill circle and is fairly well marked while the renal opening is small and inconspicuous.

Radula.—The pale radula is about half as broad as long with a shallow median groove. The teeth lie in about 90 rows of about 50 lateral teeth on each side of a median tooth. This median tooth is broadish and the end turned over finishing with 4 or 5 serrulations. The first lateral teeth are somewhat similar save that they have also a short curved spine directed inwards as well as the serrulations. Passing outwards in the row the spine becomes more marked and has sharper serrulations but on one side only, finally the extreme lateral teeth are approximately triangular with one denticulate edge.

The short glans penis is sub-conical and bears minute hooks.

This species was first described by MacFarland (10) 1095 and again more fully (11) later in the same year, when he gave a description of the internal anatomy to which I have nothing to add.

Habitat.—This form is not so common as the preceding ones but is not rare during the months of April, May and June. It has been taken from Jesse Island, Brandon Island, Mudge Island and two small specimens were dredged from the Fairway Channel near Gabriola Island (Station 4).

Family DORIDIDAE PHANEROBRANCHIATAE.

Branchiae forming a dorsal tuft, but not retractile into a pocket. Two spermatothecas.

Section POLYCERIDAE.

Shape generally limaciform with appendages. Teeth differentiated. Radula often narrow.

Genus LAILA (MacFarland.)

Laila MacFarland, Proc. Biol. Soc., Washington, 1905, p. 46.

Body depressed; frontal and lateral margins narrow, set with club-shaped papillae; rhinophores retractile, clavus perfoliate, branchial plumes few, tripinnate, non-retractile into a sheath; tentacles blunt, canaliculate. A flattened submarginal ridge on each side of the anterior end of the body just behind and above the tentacles.

No labial armature nor mandibles. Radula not narrow, the rachis with a single series of flattened spurious teeth; first pleural tooth slender, hook-like, the second large, the remaining lateral teeth (10-13) smaller, flattened.

Glans penis armed.

The genus was proposed for the reception of the following form. It is allied to the genera *Triopa* Johnston and *Issa* Bergh, but differs from the first in the presence of spurious teeth on the rachis of the radula. From *Issa* it differs in the absence of mandibles, and from both in the presence of the submarginal flattened ridge or lobe.

LAILA COCKERELLI (MacFarland).

Laila cockerelli MacFarland, Proc. Biol. Soc., Washington, Feb. 1905, p. 46; Bull. Bur. Fisheries, Washington, 1905, p. 134, pl. XXVIII; Cockerell and Eliot, Jour. Malac., XII, 1905, p. 43.

Body.—The body is elongated and fairly high (about as high as wide) a little more sharply rounded posteriorly. The mantle margin while prominent is nowhere wide and the foot protrudes behind. The dorsum is slightly arched and fairly smooth with a few, about 36, small rounded tubercles. The mantle carries a number of conspicuous club-shaped papillae which may reach a length of 5 mm. and a breadth of 1 mm. at the top and even when contracted are 1 mm. long. They are closely set and arranged in a number of oblique rows 3 or 4 in each, decreasing in size from the inner ones outwards and each papilla has an axial supporting core of spicules.

Colour.—The general body colour is stated and figured by MacFarland

to be of a "yellowish white slightly translucent" whereas in the specimens I have seen alive it was quite white without a trace of yellow. Through the skin of the dorsum a network of spicules can be distinguished appearing as interlacing white lines. The clavus of the rhinophores is a deep orange red and the branchial plumes are tinged with the same colour. The tips of the papillae are also of the same deep orange red save for a terminal spot of light orange.

Dimensions.—The largest specimen examined measured 18 mm. long, 5 mm. broad and 5 mm. high.

Head.—The head is relatively large and broad, being carried forward into a sort of veil bearing papillae similar to those on the dorsum but not as big as the largest of them. The mouth opening is conspicuous with fleshy folded lips. The laterally placed tentacles are sub-cylindrical about 1.5 mm. long and have a groove along their upper surface. Just above the point of origin of the tentacles and running parallel with the mantle edge is a small but distinct sub-pallial fold which passes back along the head and a short way on to the body.

Foot.—The foot is elongated and fairly narrow, almost square in front where it is bilabiate with a projecting upper lip slightly concave. The margins are fairly broad and thin.

Rhinophores.—The rhinophores are completely retractile into a deep sheath with a quite smooth rim. The stalk is cylindrical and the perfoliate clavus slightly enlarged and tapering, of a deep orange colour and bearing 12-14 leaves.

Branchiae.—The five tripinnate branchial plumes are not retractile and arranged in a incomplete circle. They may be tinged with orange red. Within the circle lies the distinct anal papilla to the right of which is the small renal opening.

Radula.—The radula is colourless, has a wide median groove and a very characteristic shape. The teeth are arranged in 74-80 rows. The rachis possesses a series of oblong plates which in the specimens I have examined are relatively longer and more regular than figured by MacFarland. The first pleural tooth is a small longish structure, thin and curved with a small hook at the end. The second pleural tooth is strong, stout and of irregular form. At the upper end it bears two broad short claw-like processes, one directed inwards and the other outwards. The median part also has a strong thickened band. The other lateral teeth number from 10-14, are roughly diamond shaped with curved sides and they are closely imbricated forming a sort of pavement. The inner teeth bear two small points at the upper corner but these are lacking in the outermost teeth which are also less strongly developed.

The penis is long and cylindrical and armed with minute thorn like hooks.

The striking characters of this species justified MacFarland in atrributing it to a new genus (of which it is the only member so far recorded) when he first described it. He subsequently gave a fuller description of it and a figure from which it could be immediately recognized.

Habitat.—So far I have only obtained this species from under the rocks on the beach of Mudge Island. The rocks are only exposed at spring tides, covered with fucus and green algae and lie just above the limits of a *Zostera* zone. It has been obtained by MacFarland at Monterey and by Cockerell at San Pedro, California.

Genus TRIOPHA (Bergh).

Triopha Bergh. On the Nudibranchiate Gasteropod Mollusca of the Northern Pacific Ocean (Dall, Explor. of Alaska, I, Art. 6), II, 1880, pp. 261-266 (also in Proc. Acad. Sci. Phila., 1880, p. 112). System der Nudibr. Gasteropoden, 1892, p. 148. Die Opisthobranchien, Bull. Mus. Comp. Zool., XXV, 10, 1894, pp. 184-187. MacFarland, Proc. Biol. Soc., Washington, Vol. XVIII, 1905, p. 48; Bull. Bur. Fish., Washington, Vol. XXV, 1905, p. 135. Cockerell and Eliot, Jour. Malacol, Vol. XII, 1905, p. 42.

Form of body somewhat limaciform; margin of the narrow frontal lobe with a series of short simple or composite granulose appendages; margin of dorsum with nodulate or short-branched appendages; rhinophores retractile, clavus perfoliate; tentacles short, calciform, the outer margin in part cleft (auriform); branchiae of few tripinnate leaves.

Mandibular plates triangular, made up of short, closely set rodlets. Radula rather narrow; rhachis with several series (4) of spurious teeth; pleurae with several (3-18) rows of larger teeth; lateral teeth many (10-18).

Prostate gland large. Glans penis armed.

TRIOPHA ELIOTI sp. nov.

Body.—The body is stout and limaciform and fairly high. The front end rises fairly rapidly and then slopes quite gradually to reach its highest point about half way back just in front of the branchial plumes. Thence it slopes quite rapidly leaving the last quarter of the body low. A well marked veil or frontal margin is present in the form of a semicircular fold on the edge of which are about 12 small irregularly knobbed papillae. The back is smooth save for the presence of about a dozen small blunt papillae in front of the branchiae and 3 or 4 behind. The

dorsum is marked off from the sides by a low ridge which bears five characteristic processes and continues on in the line of the edge of the veil. Each process is about 3-4 mm. long and slightly curved inwards over the back. The inner surface of the process is smooth while the outer bears a double series of small blunt papillae and the top of the process is a rounded opaque knob. These processes are all about the same size and do not decrease noticeably towards the hinder end. The dorsal ridges disappear behind the last dorsal process leaving the animal with a sort of bluntly rounded tail. The sides of the body are almost upright and slightly convex; they are smooth save that in one specimen they have 4 or 5 tiny blunt papillae and are marked off from the foot by a small ridge like fold.

Colour.—The general body colour is translucent white or *very* pale yellowish white. The knob-like terminations of the dorsal processes are opaque and of a more decided yellow colour or even orange red. The back and the sides bear a number of tiny brownish spots most of which are quite tiny and also some reddish spots which are larger. They are more plentiful at the front and thin out behind the branchiae and finally there is a group of small ones at the end of the tail. The same dull light brownish colour tinges the branchiae, the papillae on the frontal veil and the clavus of the rhinophores. The branchiae and papillae of the frontal veil may be tinged with orange red.

Dimensions.—The largest living specimen examined measured 40 mm. long 10.5 mm. wide and 8 mm. high.

Foot.—The foot is elongated and fairly narrow with approximately parallel sides running off to a point posteriorly and bluntly rounded anteriorly.

Head.—The head is rounded and bears a transverse slit-like mouth. On each side is a short auriform oral tentacle with a well marked groove on its outer border.

Rhinophores.—The rhinophores are completely retractile into cylindrical sheaths which project up above the dorsum and have a slightly wavy margin. They lie just inside the dorsal ridge at the level of the hinder end of the veil. The perfoliate clavus is bluntly conical and bears about 20-25 leaves. It is borne upon a stout cylindrical stalk.

Branchiae.—The branchial plumes are five in number in all specimens save one, where a sixth is present and incompletely retractile. They have regular tripinnate branches and are entirely separate at the base. The anterior plume is median, the remaining two pairs are lateral and in the space between them lies the anal cone with a tiny renal pore at its base on the right side.

Radula.—The radula is composed of 20-22 rows. There are four

rachidian teeth; the median pair being approximately square and the two lateral ones triangular. The pleural teeth are hamate and generally five in number although in one case two rows had six and in another several rows had but four. Outside these again are 8 uncini the innermost being roughly rectangular and the outermost more pointed and thinner. The lips are guarded by a yellowish brown chitinous cuticle leaving an opening in the shape of an inverted T. This cuticle passes backwards as a deeply curved triangular plate.

This species resembles in certain respects *T. carpenteri* (Stearns) as described by MacFarland but differs in a number of points. The colour is white, not yellow, with brown markings and in some cases orange red also. The papillae on the veil are not so large and more numerous. The dorsal processes are 5 in number and of a characteristic shape unlike those figured by MacFarland (l. c. pl. XXVII) in *T. carpenteri*. The branchiae are more regular. The papillae on the dorsum are not so large or so numerous. Lastly the radula is different, for although the four rachidian teeth are very similar the lateral teeth are fewer and more constant and the number of rows of teeth is less 20-22 as against 33. The hamate teeth are 5 or rarely 4 or 6 instead of varying from 8-18 and the uncini constantly 8 instead of 9-18 so that the radula is relatively narrower. These various points are sufficient to justify placing it in a new species. In spite of small differences, *e.g.*, the slightly fewer rows of teeth and fewer papillae on the veil there does not appear to be any doubt that this animal is the same as that described from California by Cockerell and Eliot (4) as Triopha sp. As these authors point out their specimen was small but 6 mm. long, and probably immature but does not completely correspond with any of the described species. Their description fits a small individual 6.5 mm. long that I have examined. They did not deem it advisable to make it the type of a new species on the material at their disposal but the step is justifiable in view of the further quite mature specimens that have here been examined. I propose therefore to call it *Triopha elioti* in recognition of the fact that attention was first directed to it by Sir C. Eliot, K.C.M.G.

Habitat.—It is apparently a bottom living form save that one fully grown individual was obtained during the Spring tide of May 1919 under the stones on the beach of Mudge Island just above the limit of the *Zostera* zone. Specimens have been dredged in from 15-30 fathoms at Fairway Channel near Gabriola Island (Station 4) between Brandon Island and the North end of Departure Bay (Station 18), Pylades Channel (Station 29), near Maude Island, Nawhitti Bar and other points.

Family DORIDIDAE PHANEROBRANCHIATAE.

Section PSEUDORIDIDAE.

Shape doridiform; Radula varying from moderately broad to very narrow; Teeth differentiated. Ingluvies buccalis present.

Genus ACANTHODORIS (Gray).

Acanthodoris Gray, Fig. Moll. Anim., IV, 1850, p. 103; Guide Moll. Brit. Mus., 1857, p. 207. Alder and Hancock, Mon. Brit. Nudibr. Moll., VII, 1885, p. 43. Bergh, Gattungen nordisher Doriden, Arch. f. Naturgesch. XLV, 1, 1879, p. 356; Nudibr. Moll. North Pac. II, Proc. Acad. Nat. Sci., Phila., 1880, p. 237; Monogr. d. Polyceraden III, Verh. d.k.k. zool-bot Gess. Wien, XXXIII, 1890, p. 988. System der Nudibr. Gasterop., 1983, p. 158. MacFarland, Proc. Biol. Soc., Washington, Vol. XVIII, 1905, p. 5; Bull. Bur. Fisheries, Washington, XXV, 1906, p. 144.

Body soft subdepressed; notaeum thickly covered with short villi; margin of rhinophore aperture lobed; branchial plumes few, tripinnate, arranged in a circle; head wide, veliform; tentacles short lobiform.

Armature of labial disc of minute hooks below with projecting thickenings of the cuticle. Radula rather narrow; rachis naked; first pleural tooth very large, hooked, external pleural teeth few (4-8). Glans penis armed; vagina very long.

ACANTHODORIS PILOSA (O. F. Muller var ALBESCENS (Bergh).

Acanthodoris pilosa var *albescens* Bergh, Proc. Acad. Nat. Sci., Philadelphia, Pt. I, 1880, p. 97.

Body.—The body is oval slightly broader in front than behind. It is plump but not very high. The mantle is thick and wide but the foot appears to be relatively longer than in the other species of the genus for even in preserved specimens it extends beyond the limit of the mantle, from which it is sharply marked off. The whole dorsum is covered with closely set conical papillae some larger than others. They are not retractile and even in preserved specimens stick up above the general surface of the body.

Colour.—The colour agrees most closely with that described for *A. pilosa* var *albescens* by Bergh. It is white over dorsum and foot alike and in one specimen showed a faint yellowish tinge.

Dimensions.—The specimens were all small the largest measuring 13.5 mm. long by 8 mm. wide and 5.75 mm. high.

Head.—The head is broad and veliform. It passes out laterally to

form two triangular oral flaps. There is a slight notch at the front end of the head.

Foot.—The foot is well developed and has a slightly undulating margin. At the front end it is broad and oval while at the hinder end it passes off to a leaf-like tail.

Rhinophores.—The rhinophore is retractile within a low sheath with a papillated margin. The stalk is cylindrical and the perfoliate clavus is cylindro-conical with 22-24 leaves and slightly more than half the length of the rhinophore.

Branchiae.—The branchial plumes are 9 in number and not retractile. They are arranged in the form of a horse-shoe with uncurved ends within which is the low anal papilla and other papillae similar to those covering the general surface of the dorsum.

Radula.—The radula is long and narrow and folded into a deep groove. It bears 26-28 rows of teeth each row composed of one large and a series of 3-5 much smaller lateral teeth on each side. The base of the large tooth is slightly longer relative to its breadth than in other members of the genus I have examined and bears a large curved spine. The spine is strengthened by a strong ridge which runs back well on to the basal plate and bears a few irregular denticulations. These denticulations are very variable even on the same radula and may be absent altogether. The small lateral teeth are somewhat triangular in shape, weak and have no well marked thickened ridge. They decrease in size as they pass outwards. Practically the whole length of the spine of the large tooth is clear of the small ones.

The lips are provided with a labial armature composed of a large number of minute scales, some irregular and some trianglar in shape arranged in the form of two curved leaf shaped plates. There is also a ventral portion in the form of a curved plate forked anteriorly and ending behind in a blunt point.

The genital aperture lies high up on the right side just beneath the mantle and behind the level of the rhinophores. The penis is sub-conical and provided with minute hooks.

The specimens agree most closely with those from Alaska described by Bergh under the name *Acanthodoris pilosa* var *albescens* and only differ in very small points. That author has also given a very complete account of the species and its varieties.

Habitat.—The specimens have been collected on the shore at False Narrows and Mudge Island in May and also dredged near Horswell in 25 fathoms. It does not appear to be common.

ACANTHODORIS HUDSONI (MacFarland).

Acanthodoris hudsoni MacFarland, Proc. Biol. Soc., Washington, Vol. XVIII, 1905, p. 51; Bull. Bur. Fisheries, Washington, XXV, 1906, p. 144.

Body.—The body is plump and well arched, almost oval but slightly broader in front than behind. The mantle is fairly thick and wide and sharply marked off from the foot which it completely overlaps everywhere save at the posterior end during locomotion. The dorsum is covered with fine closely set conical papillae which are not retractile and give the animal a characteristic appearance usually easily seen in preserved specimens.

Colour.—The colour of the few specimens I have seen alive has been a translucent white with the clavus of the rhinophores the ends of the gills and the mantle edge of a pale lemon yellow. The yellow in one specimen was hardly discernable.

Dimensions.—MacFarland records the animal as reaching 35 mm. long, 22 mm. broad and 9 mm. high, but the largest I have measured was 30 mm. long, 19 mm. broad and 7.5 mm. high.

Head.—The head is veliform and quite broad passing out laterally into the two triangular oral tentacles. There is a notch at the front end of the head. The mouth is a small longitudinal slit.

Foot.—The foot is broad and oval rounded, slightly concave anteriorly and a little more pointed posteriorly.

Rhinophores.—The rhinophores are tapering, somewhat conical and directed slightly forwards and outwards in life. The perfoliate clavus bears about 22-24 leaves and is about half the total length of the rhinophores. It is retractile into a shallow sheath with a papillate margin.

Branchiae.—The branchial plumes are five in number and not retractile within a sheath. They lie in a complete circle enclosing the anal papilla, which is low and blunt, and other papillae similar to those of the general surface of the dorsum.

Radula.—The radula is quite narrow, folded to form a deep gutter, and with a narrow naked rachis. The pleural teeth are 7 or 8 in number, the innermost being large and the laterals much smaller. The large tooth has a quadrangular base and bears a strong slightly curved spine, on the inner margin of which are a series of tiny denticles 5-7 in number. The small pleural teeth are somewhat triangular in shape with a raised edge and they get slenderer as they pass outwards; the first and largest lies under the base of the large tooth. The spine of the large tooth only extends a short way beyond the lateral teeth.

The mouth is armed with a labial disc pale yellow in colour. The

ventral portion consists of a thickened curved piece of chitin passing backwards to a point and anteriorly as a forked extremity. On the outside and passing dorsally at right angles to the other are two curved somewhat leaf shaped plates wider at the base and narrowing off to a point each composed of a large number of small triangular denticles. The genital aperture is high up on the right side of the body under the mantle just behind the level of the rhinophores. The penis is sub conical and armed with minute hooks.

This species was first described from Monterey by MacFarland (10, 11) who has given a good description of its internal anatomy.

Habiat.—The species was obtained on the rocks of Jesse Island in April and May 1919, and from other places not recorded. MacFarland reports that it is rare and that only four specimens have been obtained. They are also rare here but I was able to get three living specimens apart from those collected previously some of which also come from Jesse Island.

ACANTHODORIS BRUNNEA (MacFarland).

Acanthodoris brunnea MacFarland, Proc. Biol. Soc., Washington, Vol. XVIII, 1905, p. 52.

Body.—The body is somewhat oval in outline but markedly broader in the front than at the hinder end. It is also not so high as in other Acanthodorids. The mantle is wide and thick and covers the foot everywhere save at the posterior end in locomotion. The whole of the dorsal surface is covered with papillae apparently of two sizes high and low irregularly arranged.

Colour.—The dorsum is a brown colour covered with specks of deep brown almost black. The rhinophores are also of this deeper colour. The front edge of the mantle, the branchiae and the tip of the clavus of the rhinophore are yellowish brown or yellow. The body and foot are greyish white.

Dimensions.—The largest specimen measured was 19 mm. long by 11 mm. wide and 7 mm. high.

Head.—The head is large and veliform with a longitudinal slit like mouth. It is continued out laterally to form two wide flattened tentacles which like the head itself are completely covered by the mantle.

Foot.—The foot is long oval and tapering, bluntly rounded in front and passing off behind into a pointed tail.

Rhinophores.—The rhinophores are retractile into a low sheath with a bluntly papillated margin. The stalk of the rhinophore is cylindrical and slightly less than half the total length. The perfoliate clavus is

cylindrico-conical with a blunt apex and bears 22-26 leaves along the edge of which is a pale yellow or white line. In life they are directed forwards and outwards.

Branchiae.—The seven branchial plumes are not retractile into a sheath and in life wide spreading. They lie in an incomplete circle within which lies the anal papilla. As noted they are of a yellowish colour particularly towards the tips.

Radula.—The narrow radula is folded to form a deep groove and bears 30 rows of teeth. As in other Acanthodorids there are no median teeth and the first lateral is much larger and of a different shape from the remainder. The large tooth has an angular quadrilateral base and a well marked spine. The lower portion of the base is considerably thickened. The spine is strengthened at its origin by a ridge which is continued as a row of 14-17 small denticles. The remaining pleural teeth 6 or 7 in number are quite small elongate and bear a ridge on their outer sides. They are long triangles with rounded corners at the base and decrease in size as they pass outwards.

The labial armature is incomplete above and composed of a number of small closely packed plates. Below it is transformed into a single concave plate like thickening.

The genital aperture is high up on the right side of the body below the mantle and behind the level of the rhinophores. The end of the glans penis is furnished with a few minute hooks.

The species was first described from Monterey by MacFarland (10) who later (11) gave a very good account of its internal anatomy.

Habitat.—It has been dredged in about 15 fathoms in Nanoose Bay and also collected at False Narrows and Mudge Island but is nowhere common.

ACANTHODORIS NANAIMOENSIS sp. nov.

Body.—The body is plump, well arched and almost oval but slightly broader in front than behind. There is a wide moderately thick mantle present that completely covers the foot save for a small tail at the end during active movement. The dorsum is covered with numerous fine closely set conical papillae in a manner typical of the Acanthodorids. On the whole it resembles *A. hudsoni* in shape save that it is larger and plumper.

Colour.—The whole of the dorsum is of a pale dusky brownish mauve which causes the white papillae to stand up in marked contrast. The tips of the branchiae are of a port wine red colour. The sides of the body and the foot are of a dull greyish white. Save for the fact that they get

somewhat paler these colours are retained for some months after preservation.

Dimensions.—The largest specimen measured while living was 39 mm. long by 25 mm. wide by 16 mm. high.

Head.—The head is very well marked, broad and veliform with a smallish longitudinal slit-like mouth. There is a distinct notch at the front end of the head and the sides of the head are continued out laterally into two large, elongated triangular oral tentacles which curve backwards.

Foot.—The foot is not very broad, of an elongated oval shape, distinctly concave anteriorly and passing back to a bluntish point.

Rhinophores.—The rhinophores are retractile into a low sheath with a papillated margin. The rhinophores are directed forwards, outwards and upwards in life and about half their length is formed by a cylindrical stalk. The perfoliate clavus is a long, blunt ended cone bearing 28-30 leaves.

Branchiæ.—The branchial plumes are nine in number and arranged in the form of a complete circle and are not retractile within a sheath. The low, blunt anal papilla lies in the centre of the circle and is surrounded by numerous papillae similar to those over the rest of the dorsum only, if anything, slightly larger.

Radula.—The yellow radula is long and narrow and infolded into a deep grove. The rachis is narrow and bare. There are no median teeth and the lateral teeth are 6 or 7 in number and the total number of rows is 35. Of the teeth the innermost is larger and different from the rest. It has a broad almost triangular base much thickened on its inner corner; its antero-lateral corner bears a strong curved spine which although strengthened by a ridge shows no signs of denticulation and projects a good way beyond the laterals; its postero-lateral corner also bears a small but broad triangular tooth-like plate. The first five smaller teeth are roughly triangular in shape with a raised ridge on their outer border, the ridge bearing about half way along a prominent triangular point. The outermost pleural tooth, apparently not always present, is a much smaller, almost quadrilateral plate.

The labial armature takes the form of a disc composed of a large number of closely packed tiny triangular denticles. There is also a ventral curved plate of chitin pointed anteriorly and bifid posteriorly. It is fairly similar to the corresponding structure in *A. hudsoni.*

The genital aperture is high up under the mantle on the right side of the body just behind the level of the rhinophores. The penis is fairly long, sub-conical and armed with minute hooks.

The present species although in general form is somewhat like *A. hudsoni* but higher and plumper and differently coloured. The branchiae,

rhinophores and radula also differ not only from that species but also from any others that have been described previously. It is therefore listed here as a distinct species under the *Acanthodoris nanaimoensis.*

Habitat.—The individuals of this species were obtained in April from the rocks of Jesse Island and also from the Lagoon near Hammond's Bay. It is apparently not common since it had not been collected previously and only four specimens were obtained.

Genus LAMELLIDORIS (Alder & Hancock).

Lamellidoris Alder and Hancock, Brit. Nud. Moll. Pt., VII, 1855, p. 42; Bergh. Syst. der Nudibr. Gstero., 1892, p. 155-165; Proc. Acad. Nat. Sci. Phila., 1879, p. 211-216; Bull. Mus. Comp. Zool., Harvard, p. 191; Eliot. Brit. Nud. Moll., Pt. VIII, 1910, p. 155.

The dorsal surface is granulate or tuberculate; the margins of the rhinophore openings are smooth. The head is broad, crescent-shaped with the corners produced into tubercular processes. The branchiae are simply pinnate, rather numerous and set in a horse shoe. There is no regular labial armature, but the oral cuticle is armed with a ring of papillae and two ridges. The radula is very narrow, consisting only of two teeth on each side of the rhachis, the inner large and the outer small. There is sometimes a rather imperfectly formed median tooth and sometimes none at all.

LAMELLIDORIS BILAMELLATA (Linnaeus).

Doris bilamellata Linnaeus, Syst. Nat., 12, Ed. v. i, p. 1083.

Doris bilamellata Alder and Hancock, Brit. Nud. Moll., Pt. VI, 1984, Fam. I, pl. II.

Lamellidoris bilamellata (L) *var pacifica* Bergh. Proc. Acad. Nat. Sci. Phila., 1880, p. 62, pl. V.; Bergh, Bull. Mus. Comp. Zool., Harvard, p. 192.

Lamellidoris bilamellata Eliot, Brit. Nud. Moll., pt. VIII, 1910, p. 156.

The full synonymy of this species is given in Alder and Hancock (*l. c.*) and so need not be repeated here.

Body.—The body is sub-elliptical slightly broader in front than behind, and it is somewhat flattened. The dorsum is covered with tubercles of varying size they reach their maximum postero-mesially in the region of the branchiae and are smaller at the egdes of the mantle and anteriorly. The mantle is thickish but not very wide; covering the foot save that the hinder end of the latter protrudes during locomotion. Stout blunt spicules were plentiful in the dorsum and arranged in a radiating manner around the bases of the tubercles.

Colour.—The body colour is described by Alder and Hancock (1, pt. VI, Fam. I, pl. II) as of a "dull yellowish white marbled with umber brown; the brown markings forming three indistinct bands down the back; those on the sides are generally darkest in colour, but very much interrupted and irregular in form; that on the centre of the back is more uniform but less intense", and further it is noted that the brown markings "are very indistinct and in others entirely wanting; but specimens without markings are comparatively rare". This statement is correct as far as my own observation goes, for in several hundreds of specimens not one has been seen without markings. The description given above applies well to the lighter varieties but in darker individuals the ground colour may be of a chocolate colour. The markings that always appear to be present in varying intensities are a dark ring around the gill bases when contracted, a white patch in the middle line in front of the rhinophores and the two light bands on the dorsum running back from the rhinophores. There is a considerable amount of variation however.

Head.—The head is broad with a short veil passing off laterally into flattened fairly short tentacles directed postero-laterally. The mouth is rounded or even elongated in the transverse direction.

Foot.—The foot is elongate, oval, rounded in front and tapering slightly behind; it is not bilabiate.

Rhinophores.—The subcylindrical rhinophores are completely retractile into sheaths which have smooth non-tuberculate margins. The clavus is about two thirds the total length. It is perfoliate with 14-16 lamellae only the upper ones of which meet posteriorly and then they get shorter as they pass down.

Branchiae.—The branchial plumes vary in number within fairly wide limits, according to Alder and Hancock they may reach 29. I have never seen more than 22 but there is always more than 16. They are small and simply pinnate and arranged in a broad horse-shoe nearly straight anteriorly with the free ends slightly incurved and retractile within a correspondingly shaped sheath. The anus lies in the much papillated area they enclose.

This species was named by Linnaeus *Doris bilamellata* and is a common form on the North-west coasts of Europe. It has been described by Bergh under the name *L. bilamellata* var *pacifica* but apart from the fact that this may indicate it has been found in that region there does not seem to be any reason for creating a separate variety for it. It agrees in all respects with the description given in Alder and Hancock (Pt. VI, Fam. I, pl. II) and as far as my memory serves is the

same form that I have taken on the Devonshire coast near the Yealm and Salcombe.* It is not listed by MacFarland.

Habitat.—It has only been recorded once from this district namely from Nanoose Bay on 17, VI, 1919, where it was present in large numbers. Over a hundred specimens were taken and hundreds more could have been obtained as they were plentifully distributed in groups of from 3-16 all over the rocks in the sand bar. Although inconspicuous by reason of their markings they were nevertheless easy to find as they were spawning and the spawn is easily seen. It is in the form of a broad ribbon arranged in a compressed coil of from three quarters to one and three quarter volutions. This species characteristically spawns in groups. It would seem as if it were a common form when present but local in distribution.

Family DORIDIDAE PHANEROBRANCHIATAE.

Section GONIODORIDIDAE.

Body more or less limaciform, often with appendages. Rhinophores not retractile. Radula extremely narrow (only two or four teeth).

Genus IDALIA (Leuckart).

Idalia Leuckart, F. S., "Breves animalium quorundam . . . Descriptiones", 1828, p. 15. Alder and Hancock, Mon. British Nud. Mollusca, Pt. VII, 1855, Appendix, p. XVIII. Bergh, Archiv. fur Naturgeschichte, Heft., ii, 1881, pp. 140-181. Eliot, Brit. Nud. Moll., Pt. VIII, 1910, p. 158.

Body high, foot broad, and prolonged into a tail; Dorsal surface small. Pallial margin prominent and bearing a row of more or less elongate papillae all round. Over the mouth is an oral veil produced on either side into an indistinct tentacular expansion. Rhinophores perfoliate, not retractile. Branchiae simply pinnate, usually rather numerous (ten to eighteen). Penis armed with hooks; prostrate large. Buccal crop sessile. A small labial armature of hooks is present. Formula of radula 1+1, 0, 1+1. Inner teeth large, hamate, smooth or denticulate; outer small, flat, but generally with indications of a hook or spine.

Section (*a*) *Idalia sensu stricto* in which the centre of the back bears papillae, the labial armature is a ring, and the inner teeth are smooth or minutely denticulate.

*This I was able to verify during the Summer of 1920. It is the same form that occurs on the British Coast.

IDALIA VANCOUVERENSIS sp. nov.

Body.—The body is somewhat limaciform but stout and high, it drops away quickly behind the branchial plumes, leaving a leaf-like prolongation of the foot to form a tail. The rounded body is sharply marked off from the foot by a flangelike expansion of the latter. The dorsum is marked from the sides by a low pallial ridge which bears papillae and passes round in front of the rhinophores. The papillae on the ridge number 9 or 10; 4 around the base of the rhinophore the one in front and median to it being smaller than the others, 3 or 4 between these and the branchiae and two behind the branchiae. Inside these again and slightly median to the rhinophores is a row of 5 papillae and finally scattered irregularly in the mid dorsal region are 10-12 papillae, more numerous just in front of the gills. All the papillae are about the same size and shape being fairly long cylindrical and tapering to a blunt point. A veil is present continuing out laterally to the head in the form of two small triangular flap-like oral papillae. The genital aperture lies on the right, well down on the side and behind the level of the rhinophores.

Colour.—I have not had an opportunity of examining this species alive so cannot describe its colour. In formalin it is of a dull greyish white, faintly tinged with pink and showing no distinctive marking of any sort.

Dimensions.—The largest specimen measured preserved 18 mm. long by 9.5 mm. wide and 8 mm. high.

Head.—The head is broad and thick and bearing a longitudinal slit-like mouth. As noted above there is a small but distinct veil carried out laterally as flap-like oral papillae.

Foot.—The foot is quite large with an undulating margin that projects out beyond the body. Anteriorly it is slightly concave and posteriorly continued into a flat tail terminating in a point.

Rhinophores.—The rhinophores are cylindrical long and tapering to a blunt point and not retractile. The stalk is quite short and the greater part of its length is occupied by the perfoliate clavus which bears 28-30 deep leaves. It is apparently directed vertically and slightly upwards and outwards.

Branchiae.—The branchial plumes are simply pinnate and arranged in a broad horseshoe with slightly uncurved ends. They are fourteen in number and the anterior pairs noticeably larger than the posterior. In the space between them is the anal aperture upon a well marked cone on the right of which at the base is the renal pore.

Radula.—The quite pale teeth are arranged in 22-25 rows, each row consisting of 4 teeth. The two inner teeth are strong and hamate with

the slightly curved spine almost at right angles to the base. The spine bears a series of 5-7 small denticulations. The lateral teeth are smaller and have a curved triangular base bearing a claw-like spine.

The lips have an armature of tiny plates forming a ring.

The penis bears minute hooks.

The characters of this form are so distinctive that there is no doubt as to its belonging to the genus *Idalia* which has not been previously recorded from the Pacific coast of N. America. It is different in external features and in the radula from any other species so far described and so has been placed here as a new species under the name *Idalia vancouverensis.*

Habitat.—The three specimens examined were obtained from Rosespit at the north end of Queen Charlotte Islands on 24, 7.06 and was probably dredged in fairly shallow water of from 10-15 fathoms.

Tribe B. CLADOHEPATICA.

The liver does not form a single mass but is divided, and in the majority of families ramified. In a number of families the radula is not ascoglossan, and jaws are invariably present.

Family PLEUROPHYLLIDIDAE.

A very distinct family which has apparently been specially modified for a burrowing life. Animals of a fair size, flat, oval or tongue-shaped, and of leathery consistency. Head with a tentacular shield behind which is a sort of neck bearing retractile rhinophores. No dorsal appendages. The margin of the mantle usually bears cnidophores, and underneath it are usually branchial lamellae. Radula broad, jaws strong, liver ramified.

Genus PLEUROPHYLLIDIA (Meckel).

Pleurophyllidia Bergh, System der Nudibr. Gasterop., 1892, p. 68-72; Bull. Mus. Comp. Zol., Harvard, Vol. XXV, No. 1894, p. 159. Eliot, Brit. Nud. Moll., Pt. VIII, 1910, p. 160.

Cnidocysts and branchial lamellae are present. The anterior pallial margin forms a continuous fold behind the rhinophores, and in front of them there is usually a special prominence known as the caruncle.

PLEUROPHYLLIDIA CALIFORNICA (Cooper).

Pleurophyllidia californica Cooper, Proc. Californian Acad. Nat. Sci., Nov. 3, 1862, p. 202-207. Bergh, Weitere Beitr. z. Kenntn. d. Pleurophyllidien. Verhg. d. k. k. zool. bot. Ges. im Wien, XL, 1890, p. 3-8; Bull. Mus. Comp. Zool., Harvard.

Body.—The body is an elongated oval more obtusely rounded in front than behind. The dorsum is flat and continued out as a wide moderately thick mantle. The caruncle is small and inconspicuous. The oral shield is long and large and the lateral corners drawn out into triangular flap-like extensions. The rhinophores are close together at the anterior end and completely retractile within what is practically a common sheath formed by two curved leaves with undulating borders. Beneath the mantle is the usual series of gills. The sides of the body are well marked off from the mantle and foot.

Colour.—The colour is subject to a considerable amount of variation as Bergh has noticed, he says (3, p. 155) "So wie es eine blase Varietät der typischen Form der *P. undulata* giebt, kommt auch hier eine helle und eine etwas dunklerer vor". But the two are united by intermediate forms and represent the end forms of a continuous series. The dorsum is of varying shades of warm brown with a number of intense white lines on it. These lines start at the middle and pass outwards at a small angle and all the way down the back the new lines that commence are practically symmetrically arranged. Each white line is single at the beginning but shortly after becomes divided into two by a narrow pale brown band and finally becomes single again at the posterior end. In the middle region there are from 8-10 of these double lines on each side. A similar white line runs around the edge of the mantle, foot and oral hood; the two former remaining spearate at the posterior end. The oral veil, and the rhinophore sheath are of a greyish brown with sometimes a suggestion of reddish brown. The rhinophores themselves are dark grey speckled with brown spots and have thin longitudinal white lines. The sides of the body and the foot are of a translucent fawn colour while the gill lamellae are bright orange. Altogether it is a most strikingly coloured animal when alive.

Dimensions.—The largest individuals measured 48 mm. long by 37 mm. broad and 22 mm. high which is considerably bigger than Bergh's largest which was only 20 mm. long.

Head.—The head is thick and broad continuing out under the veil as a lateral ridge. The mouth is a relatively small longitudinal slit. Sometimes in preserved specimens the approximation of the anterior border of the foot and the oral veil almost completely hide the head.

Foot.—The foot is stout and broad. It is bluntly rounded with a median notch anteriorly and passes off behind into a fairly sharp poin which remains quite separate from the mantle beyond which it does not extend.

Rhinophores.—The rhinophores are short, stout cylindrical and re-

tractile within a common sheath. The rounded tips are smooth but just below are a series of shallow longitudinal folds.

Branchiae.—The branchiae lie on the under surface of the mantle forming a series of about 20 large and some smaller obliquely transverse gill plates. Each plate bears a series of about 30 thick side lamellae.

Radula.—The pale yellow radula is broad and contains from 22-32 rows of teeth. These consist of a median tooth and a series of lateral teeth reaching the number of about 46 on each side. The base of the median tooth is quadrangular with its anterior corners slightly produced into points. It bears a median spine with two pairs of small lateral spines and a series of 3 or 4 lateral denticles. The first lateral tooth has a triangular or polygonal base and bears a short claw like spine which is slightly serrulate on its outer side. The next lateral tooth is simple or claw-like. The succeeding laterals have also a side spine which may be double as well as the main one giving a characteristic bifid appearance and finally the outermost are simple long narrow plates.

Jaws.—The jaws are well developed each consisting of a curved leaf slightly hollowed on the posterior side. The crista connectiva is practically a straight smooth edge. The stout cutting border of the mandible is smooth and produced into a longish process on each side which is free from the remaining portion of the mandibular plate.

The tubular anal cone is situated more than half way back in the middle of the right side of the body beneath the mantle. The genital opening is large and lies on the right side just behind the flap-like extension of the oral veil.

The penis is fairly long, stout and sub-conical.

This species was first described by Cooper (5) and subsequently by Bergh (3) who gives a good account of its internal anatomy.

Habitat.—This is a common, wide spread species although nowhere plentiful. It has been dredged in Hecate Strait, between Gabriola and Snake Islands (Station 48), Pylades channel, and China Hat, in from 15-35 fathoms.

Family DIRONIDAE (MacFarland).

Body aeolidiform, the foot wide, rounded in front, the tail pointed; oral tentacles absent; head with a large veil; cerata without cnidosacs, closely arranged along the sides of the dorsum and extending forward towards the median line in front of the rhinophores. Liver lobulate, without branches extending into the cerata; rhinophores perfoliate, without sheaths; anus on right side near posterior end of body. Man-

dibles very large, the masticatory margin smooth. *Radula teeth five in each transverse row, *i.e.*, 2, 1, 2.

Genus DIRONA (MacFarland).

Dirona MacF. MS., Cockerell and Eliot, Notes on a Collection of Californian Nudibranchs, Journ. Malacology, 1905, Vol. 12 (3), p. 45. The Brit. Nudibr. Moll., Part VIII (Supplementary), 1910, p. 69.

Body broad, sub-depressed; head bearing a broad thin veil with smooth, undulating margin, in width equal to, or wider than, the foot; no oral tentacles; rhinophores perfoliate, non-retractile within sheaths; cerata large, inflated, non-caducous, arranged irregularly along margin of dorsum in a closely set series, which extends nearly to median line in front of the rhinophores. Cerata of varying size, the largest usually innermost, with smaller ones external to their bases; cnidosacs absent. Liver lobulated, but with no ramifications to the cerata. Foot broad, rounded in front, tapering behind to a short tail. Anus at the summit of a conspicuous papilla far back, on right side, just below the cerata. Lip disc covered with thick set, hair-like cuticular processes. Mandibles massive, the masticatory surface smooth, formed by a shield-like expansion which is reflected over the anterior margin of the mandible.

Radula narrow, its formula 2, 1, 2, the median tooth small, the laterals widely separate from it. First lateral depressed, of moderate size, denticulate on inner face, second lateral large, compressed, simple hamate.

DIRONA ALBOLINEATA (MacFarland).

Dirona albolineata MacFarland, Zool. Jahrb., p. 516, pl. 30.

Body.—The body is smooth and limaciform, bluntly rounded in front and somewhat sharper behind. The slightly convex dorsum bears two series of large inflated lanceolate cetara which are closely set and arranged irregularly along the sides. The inside cerata are the largest and may reach half the length of the animal whereas the outer ones are much smaller. They pass in front of the rhinophores towards the middle line but do not meet while posteriorly they meet in the middle line just in front of the tail.

Colour.—The general ground colour is a beautiful translucent pale whitish grey through which the internal organs can be faintly seen. A dead white line runs round the margin of the veil and along the median crest of the tail. A line of the same colour passes up the inside, over the top and down the outside of the cerata which are slightly flattened

* MacFarland's diagnosis reads—"Radula teeth in five transverse rows" which is obviously a slip for there are in the two species so far described from 29-35 transverse rows five in each row. The necessary alteration has been made.

antero-posteriorly; this line is shorter and narrower on the inside than the outside and forms a definite cap to the cerata. There is a small white cap to the clavus, a short narrow line on its antero-lateral margin and a wider line on its postero-lateral margin which passes down to the head and unites with its fellow in the middle to form a continuous line. In large specimens the interior of some of the larger cerata has been of a bright brownish colour which however quickly disappears in preserved specimens. MacFarland (p. 519) notes that "In large individuals the body and cerata are occasionally flecked with minute spots of pure white". I have not observed this in any of the living specimens I have seen.

Dimensions.—MacFarland (12, p. 519) gives the dimensions as follows "Total length up to 42 mm. height 8 mm. width 7 mm." but I have secured several specimens larger than this, the largest being 72 mm. long by 14 mm. broad by 15 mm. high, when measured in the living condition.

Head.—The head is somewhat squarish and broad passing forward into an undulating veil which is wider than the foot when in locomotion; the wavy margin bears a white line. No labial tentacles are present. The mouth is a longitudinal slit with thick rounded lips and when exerted as it is sometimes in preserved specimens, the powerful jaws are clearly seen.

Foot.—The foot is elongated and very broad and flat. At the front it is abruptly rounded while behind it tapers to a point and has a median dorsal ridge which bears a white line. The front margin though thickened is not divided and not notched.

Rhinophores.—The rhinophores are long, non-retractile, without sheaths, and pass forward and outward. The stalk is sub-cylindrical and about equal in length to the clavus which is deeply perfoliate having from 14-18 leaves. The rhinophores are separated by a distance about equal to the length of one of their stalks, a point that is not obvious in MacFarland's figure (l, c., pl. 30).

Radula.—The yellow radula when removed and flattened for examination is of a characteristic pear shape in outline. It is deeply grooved and bears from 29-31 rows of teeth. The median tooth is small and almost rudimentary being somewhat squarish behind and passing forward to a bluntly rounded point. The first lateral tooth is small with a depressed linear base bearing a spine on its upper end; on the inner end of the base of the spine are from 2-4 small denticles. The second lateral tooth is far bigger, stout and hamate, the base is inserted laterally and slightly curved. It bears a stout well curved smooth spine that points inwards.

Jaws.—The shell shaped jaws are very large relative to the size of the animal and the masticatory edge strongly developed and turned back

over the front margin of the mandible. The inner ventral border of this edge is thickened to form a yellowish brown tooth like prominence close to which a very tough ligament binds the two jaws together.

The penis is stout, sub-conical and covered with papillae.

This genus was first recorded by Cockerell and Eliot (4) who examined a closely related form namely *D. picta* and noted that an allied species had also been found. It had previously been recorded in MS. by MacFarland and Cockerell and Eliot name it from his MS. The genus is so peculiar that in a full and accurate description of the two species *D. picta* and *D. albolineata* published subsequently by MacFarland (1913) this author raises the genus to the status of a new family a step which appears quite justifiable.

Habitat.—MacFarland lists this species as rare. It is not common near Nanaimo but has an interesting distribution. Every year it spawns in a narrow cleft of the rocks on Jesse Island and a dozen individuals were obtained there in the low tides of May and June 1919. This Dr. Fraser informs me is the case each year. No specimens have been taken at any other place although searched for, save one that was dredged in 20 fathoms in Northumberland Channel (Station 5), or at any other time, thus constituting a curious example of limited distribution.

Family DENDRONOTIDAE.

Limaciform animals with oral veils and dorsal appendages which are usually branched and sometimes arborescent. Rhinophores retractile into projecting sheaths. Radula moderately wide or narrow. Liver divided into three portions which commonly but not invariably send branches to the dorsal appendages.

Genus DENDRONOTUS Alder and Hancock.

Dendronotus Alder and Hancock, Mon. Brit. Nud. Moll., Pt. I, 1845, Fam. 3, pl. 3. Bergh, Proc. Ac. Nat. Sci. Phila., Pt. I, 1872; Die Nudibr. des Willem Barent's, 1885, p. 25; Bull. Mus. Comp. Zool., Vol. XXV, 1894, p. 137. Eliot, Brit. Nud. Moll., Pt. VIII, 1910, p. 161.

Animals of large or moderate size. The oral veil and rhinophores sheaths bear arborescent processes. Rhinophores perfoliate. On either side of the back a single row of arborescent cerata. Radula varying from about 6, 1, 6 to 21, 1, 21. Liver consisting of a large posterior mass and two smaller anterior portions. The hepatic diverticula extend into the cerata in some cases, but not in others. The genitalia are unarmed. The hermaphrodite gland is large, and lies above the posterior liver. Prostate present.

DENDRONOTUS ARBORESCENS (O. F. Muller).

Doris arborescens Muller, Zool. Dan. Prod., 229; Fab. Faun Groenl, V. I, p. 3107.

Tritonia arborescens, Cuvier in Ann. de Mus., V. 6, p. 434, pl. 61. Gould, Invert. Massach., p. 5.

Dendronotus arborescens Alder and Hancock, Mon. Brit. Nudib. Moll., Pt. I, 1845, Fam. 3, pl. 3.

Dendronotus purpureus Bergh, Proc. Ac. Nat. Sci. Phila., Pt. I, 1879, p. 88.

Dendronotus arborescens Bergh, Bull. Mus. Comp. Zool., Harvard, Vol. XXV, 1894, p. 137. Eliot, Brit. Nudibr. Moll., Pt. VIII, 1910, p. 161.

Body.—The body is fairly long, higher than broad and with a well rounded back. The dorsum is smooth and bears two series of much branched dendriform papillae. The body is not sharply marked off from the narrow foot. A veil is present bearing two median arbusculi and three lateral ones on each side, diminishing in size as they pass out. Between the median arbusculi is a distinct papilla. Beneath the veil on the upper lip are a series of blunt papillae increasing in size as they pass from the middle line. The tentacle sheaths (*vide infra*) appear somewhat similar to the arborescent papillae. These papillae are seven in number on each side decreasing in size and complexity from before backwards. The anus is situated on a small papilla between the first and second papillae of the right side and bears at its foot a minute renal pore. The genital aperture lies just below and in front of the first dorsal papilla on the same side.

Colour.—I have not yet seen these animals alive but preserved they were of a dull opaque grey with the papillae of a dull brownish shade. According to Alder and Hancock the colour of the species is subject to considerable variation.

Dimensions.—Bergh gives the measurements of his largest specimens as 50 mm. long by 15 mm. high and 15 mm. broad. The larger of the two specimens examined measured after preservation 20 mm. long by 8 mm. high and 6 mm. broad.

Head.—The head is not conspicuous and bears the transverse slit-like mouth.

Foot.—The foot is elongated and narrow, abruptly rounded anteriorly while posteriorly it terminates in a point.

Rhinophores.—The clavus of the rhinophore is markedly perfoliated having about 20 leaves on each side. The leaves are thin and alternate in breadth. The rhinophore sheath is tall and bears at its apex 5 simple dendriform projections and gives off another more complexly branched

outgrowth about half way down its outside border so that it simulates the cerata.

Cerata.—The cerata have a very characteristic appearance. They rise from the sides of the dorsum as cylindrical processes which give off branches, themselves to divide into smaller and smaller twigs. The whole forms a delicate tree like structure which may be higher than the animal itself.

Radula.—The narrow pale yellow radula has about 45 rows of teeth. The median tooth has an oblong base and a median spine, slightly rounded at the tip and a little shorter than an equilateral triangle. Its two edges each bear a series of about eighteen fine denticles extending from near the tip right down to the shoulder. The lateral teeth are long and narrow coming to a slightly curved claw-like end. The inner side of the tooth is intact while the outer side bears at the end a series of about 6 short spine-like denticles. The lateral teeth vary in number from about 7-11.

Jaws.—The jaws are strongly developed and take up a large part of the side of the bulbus pharyngeus. They are in the form of a longish oval hollowed plate rounded at the posterior end. Anteriorly they have a median process mascatorius bearing several small teeth and having just behind it the deepest part of the hollow. Above, the plate is continued as a curved somewhat narrow superior process. Below, the plate bears a flange-like extension, the crista connectiva by means of which it is joined to its fellow.

The penis is long and subconical with no armature.

This species was named by O. F. Muller and described in some detail by Alder and Hancock (1) and again from Alaska by Bergh (2, 1879), the former of whom give a complete synonymy. The latter author gave a full description of *D. purpureus* but in a later paper (3, p. 139) says "Der *D. purpureus* ist vielleicht nur eine dunkler gefarbte Varietät (of *D. arborescens*) bei welcher noch dazu die Denticulation am Schneiderande der medianen Platten schwacher ist und weniger weit hinaus an der Spitze reicht".

Habitat.—So far only two specimens of this form have been obtained; they were dredged from 15-20 fathoms near the Ballinac Islands (Station 51) July 29th, 1914. It is interesting as it is a species widely spread in European waters and on the Atlantic coast of N. America. It has been recorded by Bergh from Knohdoubin Island, Bristol Bay and near Hagemeister Island in Alaska and as *D. purpureus* from off Port Moller on the N. coast of Alaska peninsula. The present record extends the southern limit of the species.

DENDRONOTUS DALLI (Bergh).

Dendronotus dalli Bergh, Proc. Ac. Nat. Sci., Philad., Pt. I, 1879, p. 94; Bull. Mus. Comp. Zool., Harvard, Vol. XXV, 1894.

Body.—The body form is somewhat like that of the preceding species but longer and more slender and not strongly marked off from the foot. There is a considerable difference however in the dorsal papillae which are not so high nor nearly so much or finely branched in any of the six specimens I have examined. Also the first is separated from the rhinophore sheath and from the second by a relatively larger distance than in *D. arborescens*. The veil is present but not very strongly marked and bears but three arbusculi on each side of which the outermost is somewhat the largest. A median papilla is absent. The upper lip bears a few small blunt subconical papillae. The rhinophore sheaths are quite large. There were four pairs of dorsal papillae present save in one specimen in which there was an additional pair but in all cases the posterior pair was very small. The anal papilla lies between the first and second papillae, *i.e.*, about half way along the back of the animal and bears at its base a small renal pore. The genital aperture lies just below and in front of the first papilla on the right.

Colour.—I have not examined this species alive but two of the preserved specimens were of a pale reddish brown with more strongly coloured papillae. The others were of a dull indifferent grey.

Dimensions.—The largest specimen measured, preserved, 31 mm. long by 9 mm. high by 6 mm. wide which corresponds fairly closely with the measurements given by Bergh.

Head.—The head is small and has a more or less circular mouth opening.

Foot.—The foot is long and narrow, abruptly rounded in front and with a distinct tail like prolongation behind.

Rhinophores.—The clavus of the rhinophore is almost conical and perfoliate but the leaves are not so deeply cut as in *D. arborescens* and it bears from 12-15 leaves. The top of the rhinophore sheath bears four or more usually five slightly dendriform papillae of which the posterior is distinctly longer than the others—a character not marked in *D. arborescens*. The sheath bears a dendriform appendage at its base on the outer side.

Cerata.—The dorsal papillae in this species are not nearly so much branched nor are the branches so long or so fine as in the preceding species. The posterior ones as already noted are very small and almost unbranched.

Radula.—The narrow pale yellow radula bears a median line of teeth

flanked by lateral teeth. The median tooth has an oblong base and a median spine which is almost equilateral but slightly asymmetrical. The sides of the spine bear only a short row of minute denticles not nearly so extensive or well marked as those present in *D. arborescens* and the whole tooth is of a slightly different shape. The lateral teeth are somewhat similar to those of the preceding species but relatively larger and slightly curved and claw-like at the end. The outer surface bears a series of about seven small spine like denticles but they are subject to considerable variation in size, shape and numbers and may fail altogether. The radula is composed of from 38-40 rows and the lateral teeth number from 10-14 on each side.

Jaws.—As in the preceding species the jaws are well developed and they are of very similar shape. In the specimens examined the plate was relatively slightly narrower and the superior process more developed.

The penis is moderately long, sub-conical and unarmed.

This species was named by Bergh (2) from a large bulbus pharyngeus that was obtained by Dr. Wm. Stimpson. The same author subsequently described the species more fully from two preserved individuals. Although he describes them fairly fully he says also in the same paper "Der *D. dalli* is ebenso vielleicht nur eine blosse Varietät (of *D. arborescens*) bei der jede Spur von Denticulation des erwähnten Schneiderandes fehlt". This is apparently accepted by Eliot who does not give *D. dalli* as a species in his list. The question of what constitutes a species is often a difficult one but in the present instance I think that there is no doubt that *D. dalli* is to be regarded as a distinct and valid species. Apart from the slight differences in the radula (fewer rows, more lateral teeth, different denticulation on the spine of the median tooth, etc.) it is always possible to distinguish the species externally; indeed they can be separated from *D. arborescens* without hesitation by a person unfamiliar with them and this I submit is sufficient to justify regarding them as separate even if closely allied species.

Habitat.—They have been dredged from various points in from 10-40 fathoms including Halibut Bank, Nanoose Bay, between Jesse and Newcastle Islands, and Gabriola Pass.

DENDRONOTUS GIGANTEUS sp. nov.

Body.—The body is fairly stout, long and high; it is considerably higher than broad and not sharply marked off from the foot although more so than in *D. arborescens*, owing to the fact that the foot has a wrinkled margin around which runs an opaque line of dead white. The

back is well rounded and smooth, high in front and dropping fairly rapidly in the region of the fourth pair of papillae. A veil is present which has three dendriform appendages on each side of which the outermost may be divided into two almost from the base. Under the veil and upon the upper lip are a large number of papillae roughly arranged in rows. The uppermost usually six in number are slightly branched, the next row, five or six in number, less branched and finally a lower row or two of from ten to eighteen small simple conical papillae. The tentacle sheaths are branched and somewhat similar to the dorsal papillae. The dorsal papillae themselves are seven in number one each side getting smaller and less dendriform from before backwards. The anal papilla is a short truncated cone with a plicated opening lying between the second and third papillae on the right side and slightly more towards the median line. The small renal pore lies at its base. As customary the genital aperture is situated below and just in front of the first papilla and nearly always the penis is extruded upon fixation.

Colour.—The colour of the body varies from a translucent greyish white to quite a dark muddy colour and the arborescent papillae, while the same colour at the base, become browner as they branch until finally most of the tips are quite opaque, either a deep brown black or pale chrome yellow. The body is not sharply marked off from the foot but around the edge of the foot is a narrow line of opaque white which starts at the edge of the veil. A similar white line frequently surrounds the anal papilla. The papillae on the veil are also tipped for some distance with opaque white or pale chrome yellow.

Dimensions.—Although a number of individuals of this species are only of moderate size it may reach what is, for a nudibranch, enormous dimensions. The largest specimen measured alive was 140 mm. long by 43 mm. high by 33 mm. broad and after preservation it measured 114 by 36 by 28 mm. A preserved specimen in the laboratory obtained by Dr. C. M. Fraser in 1913 measures 210 mm. long by 84 mm. high by 55 mm. wide. Allowing for approximately the same amount of shrinkage this must have reached the size of almost 260 mm. long by 100 mm. high and 65 mm. broad.

Head.—The head is moderately large, not sharply marked off from the sides of the body but distinct from the foot. The mouth appears as a longitudinal slit. Sometimes on killing, the pharynx is excerted showing the edges of the brownish yellow jaws.

Foot.—The foot is elongated and narrow rounded off anteriorly and terminating posteriorly in a fairly sharp point.

Rhinophores.—The conical clavus of the rhinophore is perfoliate and bears from 16-18 leaves which like those in *D. arborescens* alternate in

breadth over the greater part of the length of the clavus. The stout rhinophore sheath bears at the top four tree-like processes; of these the antero-lateral is the smallest and the postero-median much the largest being from two to four times as long as the smallest. At the base the side of the sheath is a dendriform appendage similarly situated but relatively much coarser than in *D. arborescens*. From this form the present species can be at once distinguished by the fact that the posterior edge of the rhinophore sheath bears a series of from 3-5 small but well marked dendriform papillae.

Cerata.—The dorsal cerata of this species can be readily distinguished from those of the two preceding species from the much stouter structure of their main stems and this is to be found even in small individuals. They are in all cases large but may be considerably inflated. The terminal branches are quite fine and as noted before of an opaque dark brown or pale chrome yellow. They usually contract considerably on preservation leaving the cerata as stout projections with stout fluffy branches. The first pair of cerata are the largest and lie about $\frac{1}{3}$ of the way back. The second are slightly smaller and over $\frac{1}{2}$ way back. The distances separating the others diminish fairly regularly and the last pair are quite small and fairly simple. The first three or four pairs arise as practically two main trunks right from the back and each soon subdivides. The last pairs arise as single trunks. The front two pairs are capable of considerable expansion and may stand up almost half the length of the animal.

Radula.—The radula is pale yellow in colour, wider than in the two preceding species and has from 35-40 rows of teeth. The median tooth has an oblong base narrow in the transverse direction and bearing a spine. The spine itself has the form of an acute angled triangle with the long sides incurved and bearing a series of from 11-13 well marked fairly large denticles. This tooth is unlike that described for any other member of the genus. The lateral teeth number from 12-6 on each side of the median tooth. The lateral tooth is a longish rod with a very slightly curved claw-like end that has no sign of latent denticles and is more symmetrical than in other species of *Dendronotus*. At the outer edge of the radula they become very thin.

Jaws.—The jaws occupy the whole of the side of the bulbus pharyngeus and are large fairly broad plates of a yellow colour. The crista connectiva is not quite so marked as in the preceding species and the superior process is relatively not quite so well developed. The processus mascatorius is stout and bears several small tooth-like projections.

The penis is long and almost cylindrical. It is often fully extruded upon preservation and exhibits then a series of longitudinal folds.

This is the commonest Dendronotid in the vicinity of Nanaimo and smaller specimens are not infrequently dredged. It has already been noted that it is subject to considerable variation both in size and colour. The animal in external appearance, in the shape of the cerata, oral veil, and rhinophore sheaths, apart from the fact that it reaches such a large size, mark it off distinctly from any described member of the genus. These external differences are also parallel by differences of the radula and teeth so there can be little doubt that it is a new species. I have proposed the name *Dendronutus giganteus* in order to call attention to its large size.

Habitat.—The animal has been dredged in from 10-25 fathoms from a number of points; near Hall Island (Station 46), Brandon Island, Round Island (Station 9), Dodd's Narrows (Station 30), Ruxton Passage, Trincomali Channel, Port Simpson, and by far the largest specimen was brought up in a seine net close to the laboratory.

DENDRONOTUS RUFUS sp. nov.

The body in general appearance much resembles that of *Hero formosa* as depicted by Eliot (7) save that the rhinophores have a sheath and the oral veil is not so well marked but it is a typical dendronotid. The foot is not distinctly marked off from the body. The dorsum is smooth and bears two lateral series of fine branched cerata. A distinct but not well developed veil is present and bears characteristic papillae. There are four of these on each side. The innermost is simply branched with two or three small side processes, this is followed by a simple conical papilla, then by a branched papilla similar to the innermost and finally by another simple conical papilla.

The genital aperture is below and in front of the first dorsal cerata on the right and the anal papilla lies more dorsally between the first and second cerata on the same side of the body. The renal pore was not made out.

Colour.—In the living animal there is considerable range of colour variation. The general body colour varies from a translucent grey through a semi-transparent pink to a deep brick red. In the grey form the cerata were of a pale pink colour, in the pink form there was a narrow line of darker, more opaque pink, running round the edge of the foot and up around the head at the anterior end. A similar but less marked darker line was also present in the red form.

Dimensions.—The largest specimen measured 14 mm. long by 4.5 mm. high and 4 mm. broad.

Head.—The head was inconspicuous save that it was marked off by the darker line of colour passing round it as has already been noted.

Foot.—The foot was elongated and narrow and pointed posteriorly as is general in dendronotids.

Rhinophores.—The bluntly conical perfoliate clavus of the rhinophore bore from 8-10 shallow leaves which did not appear to alternate in breadth. The tip of the rhinophore when extended was about 2.5 mm. above the back. The rhinophore sheath is well developed and has at its upper extremity four simple unbranched papillae of which the postero-median is considerably longer than the rest. Low down on the side of the sheath is a simple branch.

Cerata.—The cerata of this form are quite distinctive and much more simple than in the three preceding species and more so than in a small specimen of *D. giganteus* about 9 mm. long where they already have the characteristic form and arrangement. The first pair of cerata reached a height of 2.5 mm. The front two pairs each consisted of three main stems joining together near the point of origin and bearing from 3-5 simple papillae. The third pair likewise had three main trunks only one of which bore papillae. The fourth pair had two main trunks one of which had two papillae and the fifth pair were simple projections without papillae.

Radula.—The very pale radula had from 32-35 rows of teeth. The median tooth resembles most nearly that of *D. arborescens* from which however it differs in certain respects. It is broader, the length to breadth ratio being about 5.4 whereas in the latter species it is about 13.9. Again in *D. arborescens* the spine is almost an equilateral triangle though somewhat asymmetrical while in the present species it is practically symmetrical and shorter than an equilateral triangle. Then again the denticles on the side of the spine are relatively much larger and extend further up towards the point. The lateral teeth number from 6-8 and are relatively stouter. Their ends are well curved and bear 3-6 denticles.

Jaws.—The jaws are strong and occupy the side of the bulbus pharyngeus which measured 1.8 mm. long by 1.4 mm. wide. The processus mascatorios and crista connectiva are but poorly developed while the superior process is relatively quite long.

This species is quite obviously a dendronotid but it differs in a number of points from other members of the genus described and appears to be sufficiently distinct to be regarded as a separate species for which I have suggested the name of *Dendronotus rufus* since the prominent colour is pink or red.

Habitat.—The specimens of this species so far taken have come from between Brandon Island and the head of Departure Bay and from

Nanoose Bay in from 12-20 fathoms. They were brought in alive and kept so some hours before preserving. The smallest specimen which was about 6 mm. long was nevertheless conspicuous on account of its bright colour.

Family TETHYMELIBIDAE (Eliot).

Head broad, surrounded by a funnel shaped velum or hood; no radula; dorsal appendages foliaceous.

Genus CHIORAERIDAE gen. nov.

No radula; no jaws; dorsal appendages large foliaceous and with no sign of branchial tufts. Foot narrow. No rhinophores.

CHIORAERA LEONINA (Gould).

Chioraera leonina Gould, "United States Exploring Expedition". Adams, "Genera of Recent Mollusca", 1858, Vol. II, p. 71 and 633. Cooper, Proc. Cal. Acad. Sci., Vol. III, p. 60.

Chioraea leontina Fewkes, "New Invertebrata from the Coast of California", 1889, p. 45.

Body.—The body is fairly long limaciform and rounded. The dorsum is not sharply marked off from the sides but the line of junction is indicated by the insertion of five pairs of foliaceous appendages. The head is provided with a large sub-globular velar hood which is bilobed and has a deep notch at the front. The inner margin of the hood is provided with a double ring of tentacles. On the dorsal side of the hood are a pair of auricular appendages in the form of semi circular flaps which have no sign of short tentacles as in *Tethys*. The junction of the hood and body is marked by a distinct constriction or "neck". The anus is a small circular opening lying on the dorsum slightly to the right of the middle line and somewhat nearer the second than the first dorsal appendage. The genital aperture is also inconspicuous and is situated on the right side of the body at the front end just in the bend of the neck.

Colour.—The whole animal is of a very pale yellowish or whitish grey but is gelatinous and so transparent that most of the internal organs can be seen through it. It is marked by a ramifying series of fine more opaque lines which form a network all over the body and dorsal cerata and partly into the hood.

Dimensions.—Gould (9) records a specimen of 5 ins. in length, a size I have not seen approached in many hundreds of specimens. The body is capable of extension in life and the hood varies very much according to the amount of its expansion. The largest specimen measured alive

was body 58 mm. long by 28 mm. wide and 30 mm. high and the hood varied from 18 mm. long by 26 mm. wide to 24 mm. long by 32 mm. wide. The total length of the animal therefore was 82 mm., *i.e.*, about 3¼ ins. long. The first pair of dorsal cerata may project upwards as much as 23-24 mm.

Head.—The large head itself is composed of two large pads which together form a hemisphere with a deep longitudinal cleft, constituting the mouth, between them. It is completely enclosed by the large velar hood which as noted above is bilobed with a median notch in front and constitutes when expanded about ¾ of a hollow sphere the opening being upon the ventral side. The inner margin of the opening is provided with 44-50 close set tentacles each from 5-6 mm. long and tapering to a point. Within these again and close to them is another row of shorter, finer, more numerous tentacles. The margin of the velum is strongly contractile.

Foot.—The foot is very narrow and long. It runs the whole length of the body, is bluntly rounded anteriorly and a little sharper posteriorly. At the front end it is about 5 mm. wide and at the back about 3 mm. The edge of the foot forms a shallow flange marking it off sharply from the side of the body. As a whole it is but feebly developed.

Rhinophores.—No structures comparable with the rhinophores of other nudibranches could be found unless the cephalic appendages are their modified representative, which hardly seems probable.

Branchial cerata.—The first pair of appendages are practically symmetrically placed but the remaining appendages alternate those on the left side being slightly in front of those on the right. They diminish quite rapidly in size so that the end ones are quite small. Although large and inflated the leaves are attached by a very small area to the body and are very easily shed even in life. It is difficult in a preserved specimen to retain the full number.

Radula.—The radula and jaws or any representatives of such structures are entirely absent.

This species has been recorded by Gould (9), Cooper (5), and Fewkes (8) from Puget Sound, Santa Barbara and Monterey but has not yet been satisfactorily described or classified. It is an animal of a most striking appearance and undoubtedly allied to *Tethys* and *Melibe*. Both forms are provided with the same extraordinary cowl-like hood over the head and probably capture their food in a similar way. *Melibe* has a feebly developed pair of jaws whereas neither *Tethys* nor *Chioraera* have any sign of them. In general shape these two latter forms resemble one another fairly closely. There are however certain important differences. *Chioraera* has a relatively far narrower foot; it is higher and the

dorsum not so distinctly marked off from the sides of the body; lastly the dorsal appendages are entirely different. In *Tethys* they number about 13 pairs, are small, alternate in size and are somewhat tufted. In *Chioraera* the appendages, relatively much larger, are 10 in number, do not alternate in size and are perfectly plain. For these reasons I have placed *Chioraera* in the family *Tethymelibidae* of Eliot to indicate its similarity to *Tethys* and *Melibe* and also constituted for it a separate genus *Chioraeridae* to call attention to the noticeable differences between it and the other genera. I find myself unable to accept the classification of Bergh (3*a*) who places it in the genus *Melibe*. It is hoped to establish its relationship more securely later by further more detailed study of its anatomy.

Habitat.—There seems little doubt that this species is mainly pelagic for it is found floating freely in the sea during the early months of the year and I have seen it at the end of July and middle of August. Towards the middle or end of May however it comes in to spawn and it is then very plentiful. One spawning place is the Zostera bed round the Station float and another is on a similar bed on Mudge Island. Apparently it comes to the former a week or so earlier than the latter. At this time the animal is present in hundreds and so constitutes an extremely common form at these two points. Even then however it does not creep about on the eel grass but only seems to adhere for the purpose of laying its eggs. In the laboratory too it does not creep on the sides of the aquaria and only rarely clings to them. It has not been observed creeping on anything after the manner of other Nudibranchs and if not entirely a pelagic form like *Phyllirhoe* it is beyond doubt very nearly so and is a most interesting form.

Family AEOLIDIDAE.

Limaciform animals bearing unbranched cerata on the dorsal surface. The liver is represented by the diverticula which these cerata contain, and does not, as in *Dendronotidae*, etc., form masses in the body cavity. Rhinophores simple or perfoliate, but never with sheaths. Radula uniseriate or triseriate. Cnidocysts usually present.

a TRISERIATAE.

Each transverse row of the radula contains three teeth.

Genus CORYPHELLA (Gray).

Coryphella Bergh, Malakol. zool. Blatter, II, 1875, etc. Alder and Hancock, Monog. Brit. Nudibr. Moll., Pt. VII, 1855, p. 49. Vayssière Anal. Musée d'Hist. Nat. de Marseille. Zool., Vol. III, 1866-1889.

Eliot, Notes on some British Nudibranchs, Jour. Mar. Biol. Assoc., Vol. VII, No. 3, 1906, pp. 334-382; Brit. Nudibr. Moll., Pt. VIII, 1910, p. 168.

Form elongate and slender; corners of foot produced; rhinophores usually smooth and wrinkled but may be perfoliate jaws with several rows of denticles.

CORYPHELLA FUSCA sp. nov.

Coryphella sp. Bergh, Proc. Ac. Nat. Sci., Philadelphia, Pt. I, 1879, p. 78.

Body.—The body is elongated and limaciform and passes backwards to a blunt tail. The back is broad and curved and marked off from the almost vertical sides. The sides are sharply marked off from the foot by a flange like expansion of the latter. The numerous cerata are long and cylindrical and arranged in a continuous close set of double or treble groups. The dorsal ones are longest while the lateral ones are quite short papillae; altogether there are between 35 and 50 on each side. They do not commence until behind the rhinophores and pass almost to the posterior end leaving only a short tail. The front end is very characteristic owing to the presence of three pairs of long processes, the rhinophores, the oral papillae and a papilla like outgrowth of the front end of the foot and also the peculiar triangular shaped head shield.

The general body colour is of a transparent grayish white. The cones of the cerata are of a deep brown colour and they are capped with dense opaque white. In some specimens there is a small inconspicuous crescent shaped area of a dull orange colour in the mid dorsal line just behind the rhinophores. A thin opaque white line runs up the posterior border of the rhinophores and another on the oral tentacles, spreading out on the latter in the form of a series of tiny white dots over the distal third of its length. A similar opaque white line runs forward for a short distance from the tip of the tail and then bifurcates to end each side at the leval of the hindermost cerata.

Dimensions.—The largest specimen measured preserved 19 mm. long by 9 mm. wide and 9 mm. high.

Head.—The head is transformed into a very striking triangular cephalic shield with the apex directed dorsally. This apex is sometimes turned up over the back looking not unlike a blunt median papilla. The base of the triangle is parallel with the front edge of the foot. The mouth appears as a circular opening in a triangular depression on the head shield. About midway up the sides of the triangle come off two quite long oral tentacles which pass upwards and outwards.

Foot.—The foot is fairly narrow passing off to a point behind. It has a fairly wide undulating flange along each side. The front end is rounded

off and its corners produced outwards into longish curved tentacles.

Rhinophores.—The rhinophores are long and non-retractile. They lie at the front of the dorsum, anterior to the cerata and slightly median to the continuation forward of their line. The perfoliate clavus occupies more than half the length of the rhinophore and contains 32-38 shallow leaves.

Radula.—The pale radula is narrow and short and bears 19 rows of teeth each composed of three teeth. The base of the median tooth is somewhat horse shoe shaped. There is a long well developed sharply pointed median point. On each side of the median spine are a series of lateral denticles which are subject to a certain amount of variation; thus while the most common number appears to be six on each side, teeth are present with five only on each side, 4 on one side and 6 on the other or even 7 on one side. The lateral teeth have an irregularly triangular base with a long sharp lateral spine. On the inside of the base of this spine are a series of denticles varying in number from 5-3, 4 or 5 being the commonest number.

Jaws.—The jaws are well developed, of an oval hollow shell shape and yellow colour. The crista connectiva is fairly well developed and the masticatory edge quite strong and brown in colour. The edge bears a number of tiny slightly curved spine like denticles arranged in four or five rows some considerably higher than the others.

There is no doubt that this is the same form that Bergh (2) described as *Coryphella* sp. from a single bulbus pharyngeus dredged in 9-16 sp. fathoms off the Aleutian Islands. It agrees exactly with it in the form of the radula and the jaws. It is also clear that not only in these points but also in its general external appearance and internal anatomy it corresponds quite closely with the typical members of the genus although differing sufficiently to merit its being considered as a separate species. In one point however it differs rather strikingly from other species of the genus and that is the character of the rhinophore. Both Bergh and Eliot state that a diagnostic character of the genus is the possession of a smooth or wrinkled or at any rate a non perfoliate rhinophore. The present species has undoubtedly got a perfoliate rhinophore with 32-38 distinct but moderately shallow leaves. So closely does it approximate to other members of the genus that it does not appear justifiable to place it in a new genus and consequently I have altered the diagnosis of the genus to "rhinophores usually smooth or wrinkled but may be perfoliate" in order to include it. It is here described under the name *Coryphella fusca.*

Habitat.—This species is not rare and appears to be the commonest Aeolid in the neighbourhood. It has been dredged in from

10-25 fathoms off Neck Point, Oyster Harbour, Protection Island, West Rocks, Esperanza Inlet, between Brandon Island and the head of Departure Bay, Nanoose Bay and the head of Departure Bay.

CORYPHELLA TRILINEATA sp. nov.

Body.—The body is elongated and typically Aeolidiform and passes back to terminate in a fairly well defined tail. The back is curved and passes round into the almost vertical sides. The sides of the body and foot are not separated by so well marked a flange as is the case in *C. fusca*. The papillae are fairly numerous, approximately conical but wider at the distal extremity where they terminate bluntly. They are arranged in groups and the most anterior is behind the level of the rhinophores. They number from 32-34 on each side. The first group of cerata is composed of from 7-9. The remaining somewhat smaller ones about 25 in number are in 3 or 4 very ill defined groups. A triangular head shield similar to that in *C. fusca* is lacking.

Colour.—The general colour of the body and tail is a pale whitish grey, and this also is true of the cerata which are however very transparent. There is a narrow opaque white line running from the tip of the tail forwards up the mid dorsal line to just in front of the rhinophores, here it bifurcates and passes out practically at right angles to the blunt oral tentacles over which it spreads out to form a uniform but less intense covering. A similar narrow white line runs back on the side of the body from behind the rhinophores to the tip of the tail. The cores of the cerata are of a bright brick red colour and expand into a knob at the end around which is a ring of darker red. The clavus of the rhinophore is yellowish.

Dimensions.—When alive the single specimen examined measured 6.5 mm. long by 2.5 mm. high and 2 mm. wide.

Head.—The head is relatively large and sub globular not passing into a dorsal peak at the sides it bears two wide flat almost triangular tentacles not at all like those of *C. fusca*.

Foot.—The foot is fairly narrow, wider in front and passing off to a sharp point at the tail.

Rhinophores.—The non-retractile rhinophores have no sheath and are fairly long. They lie inside and in front of the first group of cerata. The clavus occupies more than half the total length and is perfoliate with 10-12 very shallow but nevertheless distinct leaves. It terminates in a bluntly rounded end.

Radula.—The very pale yellow radula is narrow and composed of 24-26 rows of teeth, three in a row. The median tooth has a long somewhat U shaped base bearing a median spine. At each side are 6 lateral

spines getting smaller as they pass backwards but the first on each side being almost as large as the median spine. They are relatively much stouter than in *C. rufibranchialis* which this species resembles in certain respects. The lateral tooth is in shape almost a right angled triangle with a small piece taken out at the right angle corner. The apex is continued as a sharp spine and the hypotenuse bears a series of from 8-10 small spines.

Jaws.—The jaws are quite hollow and almost circular in outline. The masticatory edge is fairly short and bears a series of tiny pointed denticles. In general form the jaws are not unlike those of *C. fusca.* The genital aperture is high up on the right side of the body about one third of the way back.

This species to a certain extent in its general appearance recalls *C. rufibrachialis* of Alder and Hancock but differs in the presence of opaque white lines, possessing a perfoliate clavus, wider flatter oral tentacles and a different type of radula. In some respects it recalls *C. lineata* but differs in shape of cerata, of oral tentacles and of the teeth. It is here described as a new species, *C. trilineata.* It will be noticed that both this and the preceding species have a perfoliate clavus with quite shallow leaves. Examination under the binocular microscope of the specimens both alive and preserved shows that they are undoubtedly perfoliate although Eliot says that is not the case in the genus. Sooner than form a new genus for this form and *C. fusca* however, I propose to place them with the other members and slightly alter the diagnosis of the genus.

Habitat.—The specimen was dredged in from 10-15 fathoms in Nanoose Bay and was kept alive in the laboratory for some hours before preservation.

Family AEOLIDIDAE.

β UNISERIATAE.

The radula consists of a single longitudinal row of teeth.

Genus AEOLIDIDA (Cuv).

Alder and Hancock, Brit. Nud. Mill., 1854, Fam. 3, pl. 9. Bergh, Beitr. z. Kenntn. d. Aeolidiaden I. Verh. d. k. k. zool. bot. Ges. in Wien., XXIII, 1874, p. 618-620—II, 1, c, XXIV, 1874, p. 395-396—V, 1, c, XXVIII, 1878, p. 822; system der nudibr. Gasteropoden (Semper Philippinen), 1892, p. 27; Bull. Mus. Comp. Zool., Harvard, XXV, 1894, p. 127. Eliot, Brit. Nud. Mill., 1910, p. 175.

Body stoutish, flattened. Corners of foot slightly produced, Rhinophores smooth. Cerata flattened. Anus dextro-dorsal. Jaws with

smooth edges. Teeth simply pectinate without any median cusp or division into two halves.

AEOLIDIDA PAPILLOSA (Linn.)

Eolis papillosa Alder and Hancock, Brit. Nud. Mill., 1854, Fam. 3, pl. 9.
Aeolidia serotina Bergh, Verk. d. k. k. zool. bot. Ges. im Wien, 1874, p. 618-620, Taf. IX and X.
Aeolidia papillosa (L), var pacifica Bergh Proc. Ac. Nat. Sci. Phila, 1879, p. 75-77, pl. I.
Aeolidia papillosa Bergh, Bull. Mus. Comp. Zool., Harvard, XXV, 1894, p. 127.
Aeolidia papillosa Eliot, Brit. Nud. Mill., 1910, p. 175.

No attempt has been made to give the full synonymy of this species which is probably that originally named by Linnaeus as the earlier part of it is fully set out in Alder and Hancock, Part VI, 1854.

Body.—The body is elongated, ovate, abruptly rounded in front, tapering to a fine point posteriorly and somewhat depressed. The numerous cerata are arranged in from eighteen to twenty lateral row each containing from twelve to eighteen. They reach well in front of the rhinophores and are arranged obliquely, leaving the dorsum free for about the front half but covering it in the posterior half of the body. They extend beyond the foot all round save its hinder tip in crawling.

Colour.—Considerable colour variation has been noted in this species but in the specimen collected the under surface and ventrally situated papillae are of a pale yellowish colour. The dorsum where clear of papillae is dark brownish becoming darker as it passes forward. At the front end is a patch of close set white specks arranged in approximately an equilateral triangle with a notch in the middle of the front; the two anterior corners are continued as white lines out on to the oral tentacles and the posterior corner continued back between the rhinophores for a short distance. The oral tentacles are white flecked with black dots more profuse at the base than anywhere else while the rhinophores are dark brown almost black up to near the tip where there is first a band of opaque yellowish white and finally a terminal transparent spot which makes them appear to be hollow. The cerata are of a dull brownish grey spotted with white. In some cases towards the posterior end and sides the white spotting is more marked and as already noted the ventral cerata are pale yellowish with some brown-grey colouration.

Dimensions.—When alive the animal measured 58 mm. long by 17 mm. wide by 10 mm. high. The rhinophores were extended to a length of 11 mm. and the oral tentacles 12 mm.

Head.—The head is short and wide and continued on laterally into two conspicuous oral tentacles which extend forwards and outwards and are constantly in motion while the animal is not moving about. They are white with a few small black spots.

Foot.—The foot is lanceolate, bilabiate and abruptly rounded in front and continued out laterally into two, not very marked points; posteriorly it is more sharply pointed. The upper lip is somewhat thicker than the lower but not notched.

Rhinophores.—The rhinophores are set on the dorsum behind the tips at the front of the foot. They cannot be retracted into a sheath and are directed upwards and slightly laterally. They are of a deep brown colour save for the yellowish white band and transparent tip. The end is quite smooth.

Cerata.—The cerata are, as noted, numerous and in rows. Each is somewhat curved with the outer side of the arch pointing laterally and capable of considerable distension. They are of a dark brownish gray speckled with opaque white but not white tipped as figured in Alder and Hancock (1 Fam. 3, pl. 9).

Radula.—The pale yellow radula contains 28 rows of teeth each row consisting of one large tooth. Each tooth is crescentric with its inner border smooth and strengthened by a ridge. The outer border bears a large series of long, closely approximated denticles varying from about 30 to 46 in number. The central point is marked by a slightly wider space separating the denticles.

Jaws.—The jaws are well developed and of a brownish yellow colour. Each is in the form of a roundish shallow shell with a strong processus masticorius marked by a series of fine longitudinal striations and rather small crista connectiva.

This species is a widespread one and if as Eliot suggests (7, p. 175) the three species so far described are probably but colour variations of the one species then it is found on the North Western Coasts of Europe; Atlantic North America (*fide* Alder and Hancock 1, Fam. 3, pl. 9); Chile and Falkland Islands (as Ae. serotina); Port Otway, Patagonia; and Santa Barbara, California. The present specimen was obtained at False Narrows, 28th June, 1919.

Habitat.—It does not appear to be a common species near Departure Bay, no other specimens having been recorded. The present one was obtained in a crack on the under side of a stone, well above low tide mark and when collected was laying its eggs. Probably another individual was also present and smashed in breaking away the rock, for another egg mass was secured and with it a number of cerata and portions

of a body of the same colour as in the individual obtained, which was not in any way injured.

Genus HERMISSENDA (Bergh).

Hermissenda Bergh, Beitr. zur. Kennt. der Aeolidiaden VI. Verh. d. k. k. zool. bot. Ges. Wien, XXVIII, 1878, p. 573. Bergh, Proc. Ac. Nat. Sci., Philadelphia, Pt. I, 1879, p. 81.

Body slender and elongated rhinophores perfoliated, tentacles elongated. The dorsal papillae are arranged in oblique transverse series and lie in close-set group.

HERMISSENDA OPALESCENS (Cooper).

Aeolis (*Flabellina*) *opalescens* Cooper, Proc. Cal. Acad., ii, 1862, p. 205; iii, 1863, p. 60.

Hermissenda opalescens Bergh, Vergh d. K. K. zool. bot ges. in Wien, XXVIII, 1878, p. 573; Proc. Ac. Nat. Sci., Philadelphia, Pt. I, 1879, p. 82. Cockerell and Eliot, Jour. Malac., XII, 1905, p. 50.

Body.—The body is elongated, slender, limaciform, not sharply marked off from the foot and without a distinct mantle. The dorsum is smooth and bears along the side a large number of cerata lying in oblique transverse series in close-set groups, the largest being on the inside and the smallest outside. The first group, containing the largest cerata and commencing lateral to the rhinophores, is always distinct from the rest and slightly raised. In young specimens or specimens that have lost a number of cerata a second and third group can also be distinguished but in older and more perfect specimens they appear to form one continuous group. The end of the foot extends beyond the region of the cerata. The cerata themselves are elongated and sub-cylindrical with a blunt point in living specimens but after preservation they are usually curved as Bergh (2, p. 83) states.

Colour.—The colour of the body and cerata is subject to considerable variation. Generally the colour is of a pale translucent grey or even bluish grey. Along the mid dorsal region runs a narrow opaque white iridescent line which passes forward from the tip of the tail to the first group of cerata. Here it bifurcates and the two branches diverge narrowing down again to pass around the inner base of the rhinophore and then turning more sharply laterally to run right up the dorsal side of the oral tentacles. Another line of similar colour commences on the ventro-lateral margin of the foot in front of the rhinophores and passes back parallel with the edge right to the tip where it also runs into the end of the mid-dorsal line. In addition to these continuous lines there is also

a similar coloured broken latero-dorsal line. This forks from the other line at the base of the oral tentacle and runs backwards and downwards below the other base of the rhinophore to the first group of cerata. It passes as a short line about 2-4 mm. long from the end of the first to the beginning of the second group of cerata and again from the last cerata for about 5 mm. to join the mid-dorsal line at the beginning of the tip of the foot. The colour of these lines is generally of an iridescent opaque white but they may appear bluish or greenish. The reason for this is apparent when they are examined under a binocular microscope when it is seen that the colour is due to an enormous number of minute dead white spots with which are mixed a lesser number of spots of intense blue and orange. This causes the iridescence and the variation in the number of the coloured spots alters the general colour of the line.

In the somewhat diamond shaped space between the branches of the dorsal line is an area of deep orange colour which may be continued a short distance in front of the rhinophores. I have not encountered a similar area slightly further back as figured by Cockerell and Eliot (4) although in some species there has been an indication of a broadening or even splitting of the mid-dorsal line.

Below the base of the rhinophore and below the broken lateral line on each side is a small oval area of bright orange. In the area in front of the rhinophores between the branch of the dorsal line and the commencement of the broken line are a number of blue spots always sufficient to give a distinct blue tinge but sometimes a deep blue area.

These markings have been dealt with in some detail because they entirely disappear a few hours after preservation and have not been satisfactorily described by Cooper, Bergh, or Cockerell and Eliot. The last two having dealt with only preserved material do not mention either the lateral line or the orange and blue lateral marks, indeed, the former of them does not mention even the mid-dorsal line. In all living specimens I have seen, 60-70 from different localities, they have been present and it is to their presence that the animal owes much of its beauty.

The cerata are of a pale translucent yellowish grey in the middle of which the liver diverticula form a core which varies in colour from a reddish to a very dark chocolate colour. A thin finely granular white opaque line passes up the outside border of the cerata and forms a cap at the top save that the extreme tip is left without pigment and so appears as if it were perforated. Cockerell and Eliot state that the cerata have "bluish tips" but I think this is a slip for they do not figure it in their drawing and it has not been noticed by any other writer. A blue tip is characteristic of *Janolus coeruleopictus*. Many of the larger cerata in the mid-body region have scattered minute spots of pale blue, pale green,

orange and opaque white giving an iridescent effect so that a well marked variety well deserves its specific name of *opalescens*.

In spite of the colour differences that have been pointed out above there is no doubt from its other features that it is the *H. opalescens* of other authorities.

Dimensions.—Cooper (5) gives the size of this animal as one and a half inches and breadth a quarter of an inch and my own measurements agree fairly well with this. The largest specimen measured 42 mm. long by 12 mm. wide by 9 mm. high.

Head.—The head is large, with a transverse slit-like mouth and its margins are continued laterally into very well developed oral tentacles, these are directed outwards and forwards in front of the head as much as 18 mm. and are constantly in motion strongly recalling the "feelers" of a snail.

Foot.—The foot is well marked, elongated and somewhat lanceolate, posteriorly it is pointed and anteriorly abruptly rounded. The front margin is bilabiate, the upper lip thin and the lower one fleshy they bear a shallow notch in the middle line. Both lips are continued out laterally into short, slightly curved horn-like processes about 4 mm. long and grooved on their antero-ventral border. In locomotion they are visible from above.

Rhinophores.—The perfoliate rhinophores are usually held erect and turned slightly outwards. They are not retractile into a sheath and the clavus occupying over half their length bears about 20-24 leaves.

Radula.—The radula is long and narrow and curved in a slight spiral. It bears from 25-27 large median teeth. Each tooth possesses a stout median cusp on each side of which are from 4-6 small pointed denticles. The under side of the central cusp is irregularly serrulate.

Jaws.—The jaws are well developed, shell-like and of a yellow horn colour. The masticatory edges are curved and their edges bear a row of about 50 short, sharp denticles which increase in length as they pass downwards and backwards, the hindermost being slightly serrulate.

The penis is long and sub cylindrical when extruded and bears a series of glandular nodules some distance from the end which are similar to those in *Facalana* according to Cockerell and Eliot (4, p. 51).

The species was first recorded by Cooper (5) and later Bergh (2) gave a fuller account of it including its internal anatomy. It has been reported from California by Cockerell and Eliot.

Habitat.—This species is quite common in the neighbourhood and to be found on the rocks above low tide level, at Jesse Island, Brandon Island, Newcastle Island, Mudge Island, Round Island, False Narrows and from the float at the Station. It has been recorded from Sitka in

Alaska and San Diego and San Pedro in California so that it probably extends along the north west coast of America. Its eggs were obtained in May and June.

Family DOTONIDAE.

Small animals agreeing with the Aeolididae in most points except that the rhinophores are protected by projecting sheaths. The cerata are stout and tuberculate.

Genus DOTO (Oken).

Doto Bergh, Malacozool. Blatter, VI, 1879, pp. 24-30; IX, 1888, pp. 695-698. Vayssiere, Recherches zool. et anatom. sur les Moll. opisthobr. du golfe de Marseille. Ann. Musee d'Hist. Nat. de Marseille Troisieme partie, Ib., Vol. VI, 1901, pp. 99.106. Eliot, Notes on some British Nudibranchs Jour. Mar. Biol. Assoc., Vol. VI, 1901, pp. 334-382; Brit. Nud. Moll., Pt. VIII, 1910, p. 166.

Rhinophores smooth (except in *D. crassicornis*) with large cup-like sheaths. Cerata arranged in a single row on either side of the back; Clavate and studded with papillae or knobs. An oral veil over the mouth with short tentacular prolongations. Jaws smooth. Radula a long row of small horse-shoe shaped teeth bearing a few denticles or ridges. In *Doto* the radula is uniseriate, but in the allied *Dotilla* there are four to five minute lateral teeth. Genitalia not armed.

DOTO COLUMBIANA sp. nov.

Body.—The body is elongated and limaciform. The back is curved and smooth save for a row of clavate cerata on each side and it is not sharply marked off from the sides of the body nor are these from the foot. The end of the body finishes off as a distinct tail clear of the cerata. A narrow oral veil is present over the head and it bears a few short papillae. The cerata number five pairs diminishing in size as they pass backwards and falling off readily during or after preservation. There are no small intermediate cerata as figured for *D. coronata* by Alder and Hancock, each is swollen and globose, attached to the back by a slender stalk and bearing 18-22 raised areas in the form of short truncated cones.

Colour.—The colour is greyish white or pale greyish yellow all over the body and foot alike. On the back and along the sides are scattered black pencillings and an edging of the same black melanphores surround the raised areas on the cerata. This black is visible some months after preservation and in formalin the whole animal often turns a dark grey.

Dimensions.—The largest specimen measured when alive was 14 mm. long by 2.75 mm. high and 2.25 mm.

Head.—The head is not well marked off from the veil and is fairly broad. It bears a small longitudinal slit-like mouth.

Foot.—The foot is elongated and gradually gets narrower from the abruptly rounded almost concave front end to the pointed tail.

Rhinophores.—The rhinophores are non perfoliate and in the form of blunt ended cylindrical rods. The part corresponding to the clavus is slightly roughened but shows no signs of leaves. They are completely retractile into prominent deep cup shaped sheaths with a smooth margin.

Radula.—The radula is very pale and even taking into consideration the small size of the creature very tiny being quite long and exceedingly narrow. It is uniseriate and bears 86-96 rows of teeth. Each tooth has a horse-shoe shaped base with a median spine and three small lateral spines. The lateral spines are situated near the apex and two near the base of the median spine. The two near the apex are asymmetrical one being higher up than the one on the other side and this arrangement is alternate. Thus if on one tooth the right one is nearer the apex than on the next tooth it is the left one and so on.

Jaws.—The jaws are fairly thin and very pale. They are oval in shape and smooth, occupying the major part of the pharyngeal mass.

The penis is short and conical and without armature.

This form is undoubtedly a member of genus Doto and so is as far as I can ascertain the first species of that genus to be recorded from the Pacific coast of North America. It is quite distinctive and differs from other species described elsewhere although it is nearly allied to *Doto coronata* and so has been here described as a separate species under the name *Doto columbiana.*

Habitat.—Three specimens were dredged in July in from 12-18 fathoms between the end of Brandon Island and the head of Departure Bay and two more in 15-20 fathoms in Nanoose Bay. They were all brought in alive and kept so for some hours before preservation.

SUMMARY.

In the foregoing list of Nudibranchiate Mollusca the following eight are placed on record as new species:

Triopha elioti, Acanthodoris nanaimoensis, Idalia vancouverensis, Dendronotus giganteus, Dendronotus rufus, Coryphella fusca, Coryphella trilineata, and *Doto columbiana.* Of these *T. elioti* and *C. fusca* have been partially described but not named, by previous workers; in the former case from badly preserved material and in the latter from a fragment but in each case insufficiently to justify the author in naming them

as distinct species. Further, satisfactory material of both has been obtained and this has been sufficient to merit their being recognized as valid species.

The species *Chioraera leonina*, previously but little known and poorly described, has been more fully dealt with and placed in a new genus. *Chioraeridae*.

The following species in the list have been recorded previously both from Alaska and California and so probably occur in suitable localities between these points: *Tritonia exsulans*, *Archidoris montereyensis*, *Diaulula sandigensis* and *Hermissenda opalescens*.

The following species in the list have been recorded previously *only* from Alaska on the Pacific Coast of North America and their range is thus extended considerably to the south: *Acanthodoris pilosa* var *albescens*, *Lamellidoris bilamellata*, *Dendronotus arborescens*, *D. dalli* and *Aeolidida papillosa*. The last named while not recorded from California has been described from Southern Patagonia and is one of the widest ranging species known, so it may occur in California.

The following species in the list have been recorded previously *only* from California on the Pacific Coast of North America and so have their range extended considerably to the north: *Tritonia exsulans*, *Anisodoris nobilis*, *Cadlina marginata*, *Pleurophyllidia californica*, *Dirona albolineata*, and *Chioraera leonina*.

Complete colour notes from living specimens have been given for the first time for the following previously noted forms: *Triopha elioti*, *Acanthodoris pilosa*, var *albescens* *Pleurophyllidia californica*, *Chioraera leonina*, *Coryphella fusca* and *Hermissenda opalescens*. Additional colour notes have been given of the other species.

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EXPLANATION OF THE PLATES.

All figures were drawn from my own preparations with the aid of a Zeiss camera lucida and at the magnifications stated.

PLATE I.

Fig. 1. *Tritonia diomedia* middle and first lateral teeth ×105.
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Fig. 3. *T. diomedia* 3 lateral teeth near outer edge ×105.
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Fig. 5. *T. exsulans* 4 lateral teeth near outer edge ×63.
Fig. 6. *T. exsulans* 4 lateral teeth next to innermost ×63.
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Fig. 10. *A. nobilis* 3 lateral teeth near outer edge ×105.

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Fig. 20. *T. elioti* sp. nov. 8 outermost lateral teeth×63.
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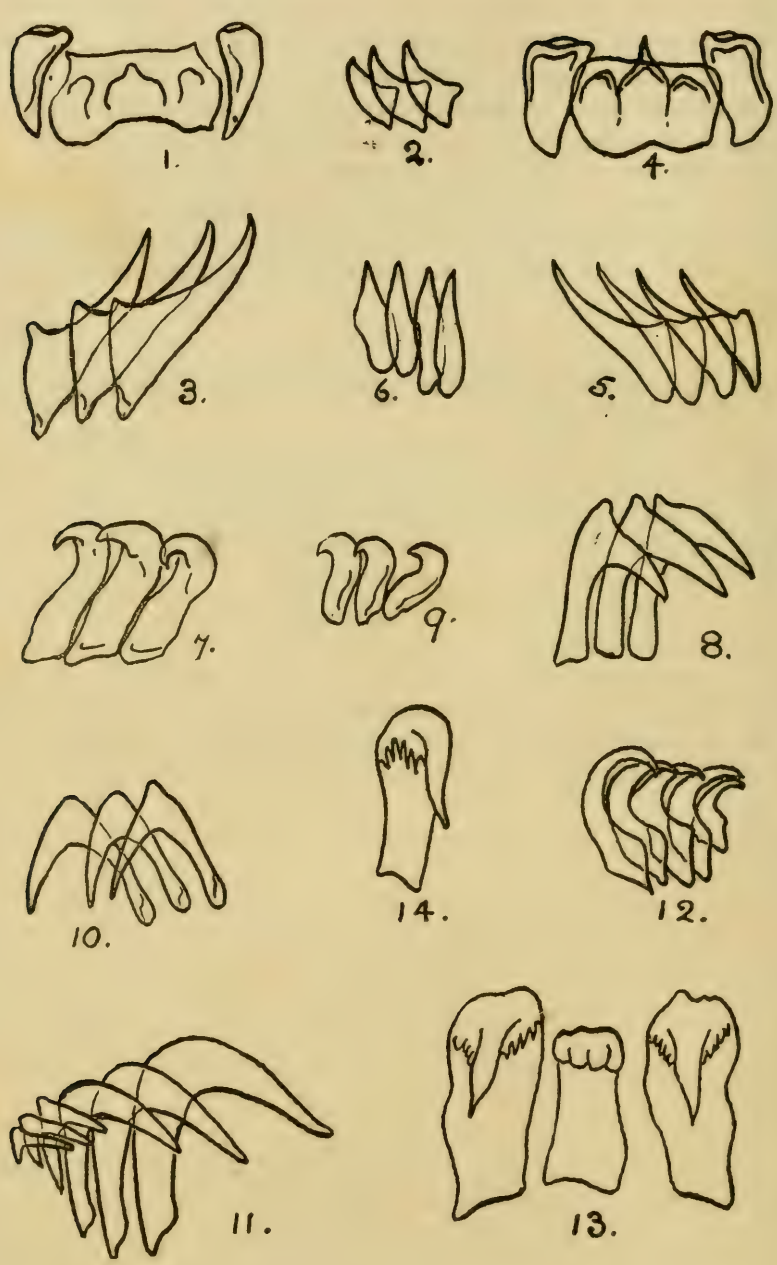
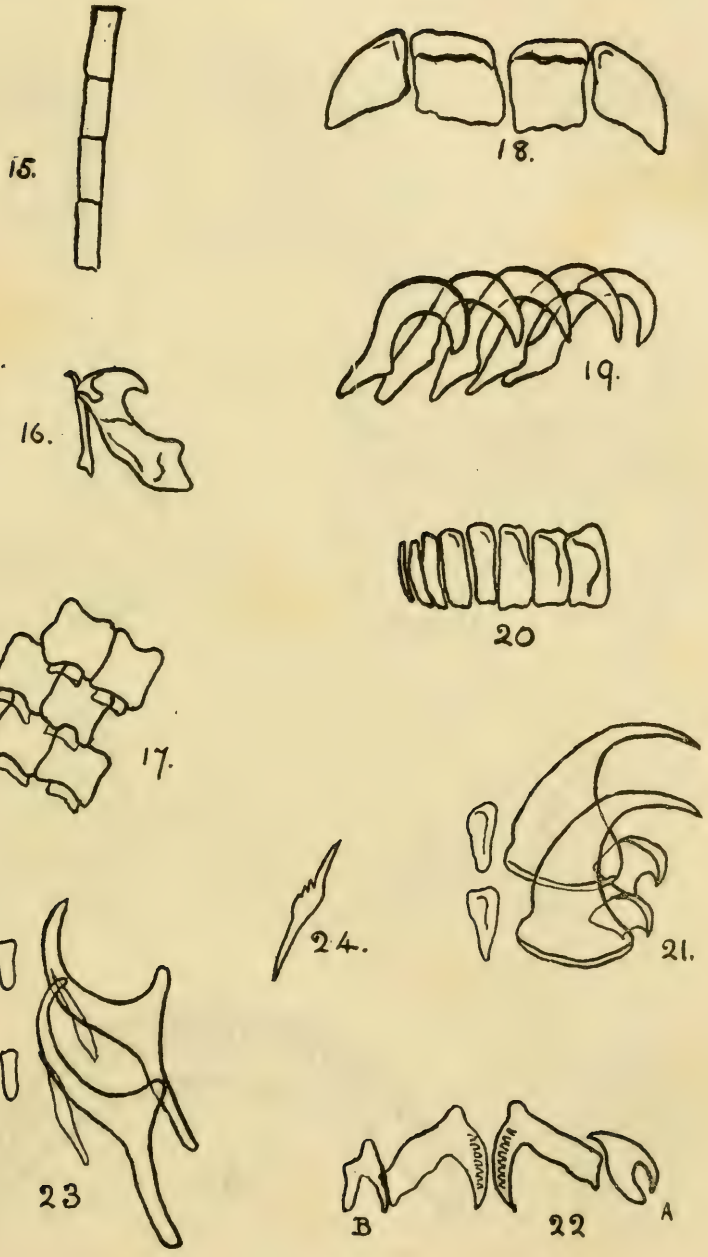
Fig. 59. *D. giganteus* sp. nov. four outermost lateral teeth×177.
Fig. 60. *Coryphella fusca* sp. nov. jaw median aspect×12.



O'Donoghue on Nudibranchiate Mollusca



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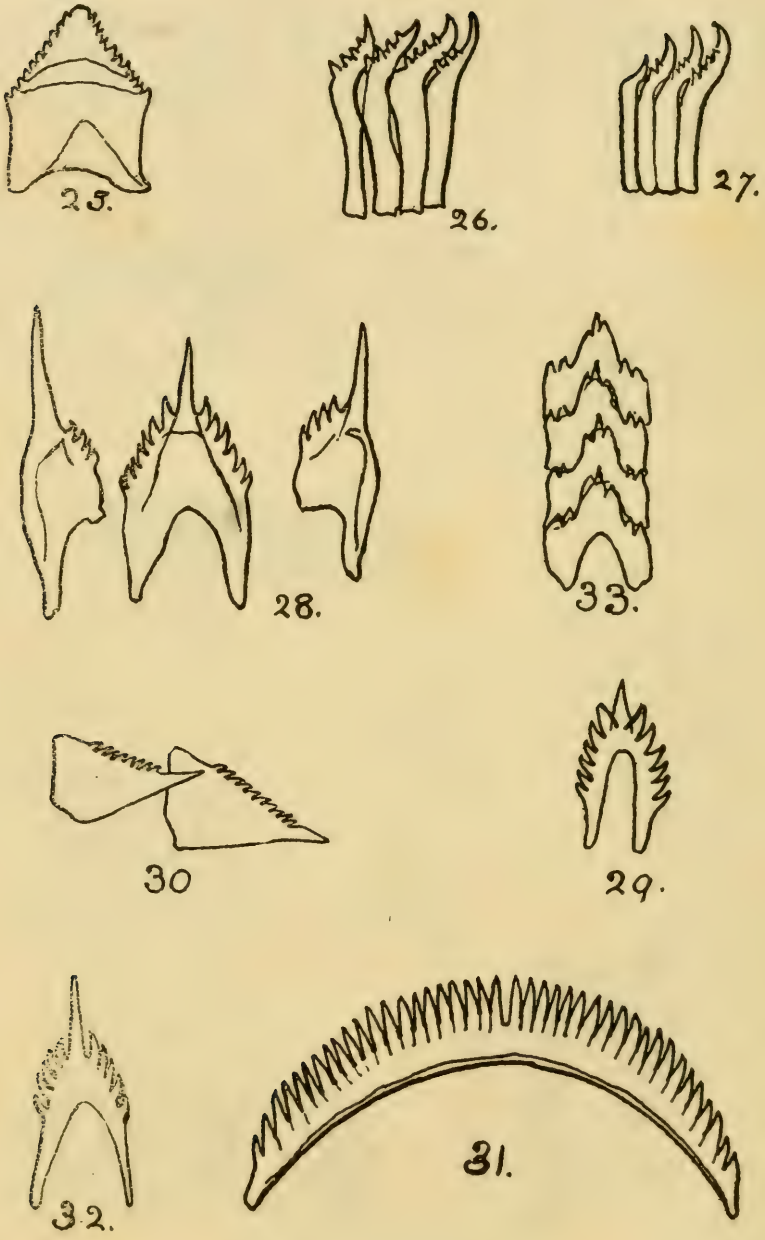
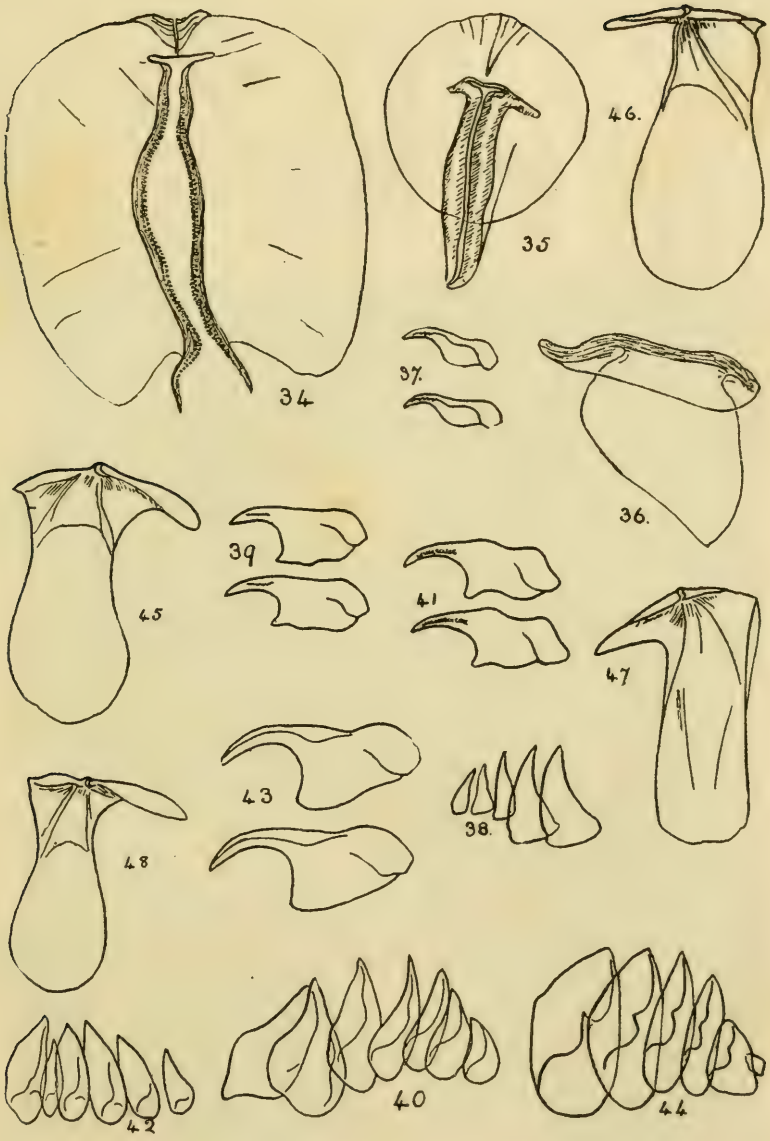
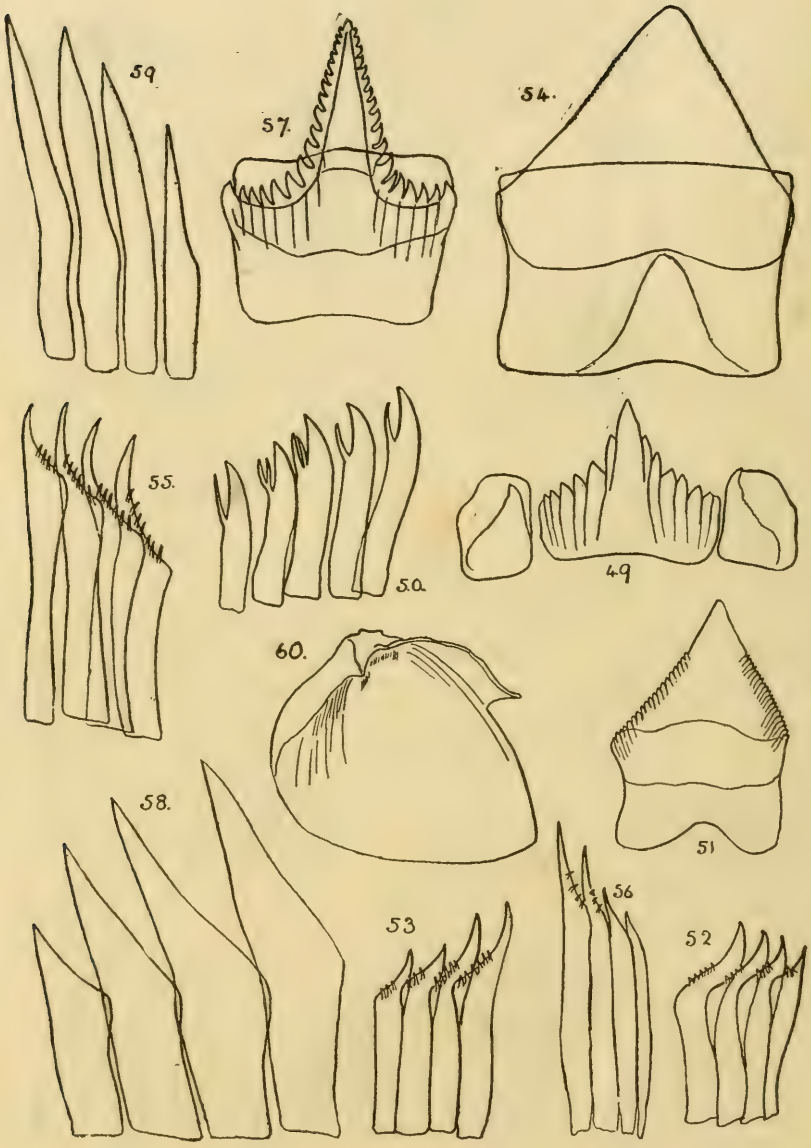


O'Donoghue on Nudibranchiate Mollusca



O'Donoghue on Nudibranchiate Mollusca



O'Donoghue on Nudibranchiate Mollusca

GROWTH IN ERIOGONUM NUDUM IN RELATION TO ENVIRONMENTAL FACTORS.*

BY FRANCIS E. LLOYD, F.R.S.C.

Material.—The growth measurements herein recorded were made on the terminal long internodes of a rosette plant, *Eriogonum nudum.* The cluster of oval leaves stands usually within 10 to 20 cm. of the

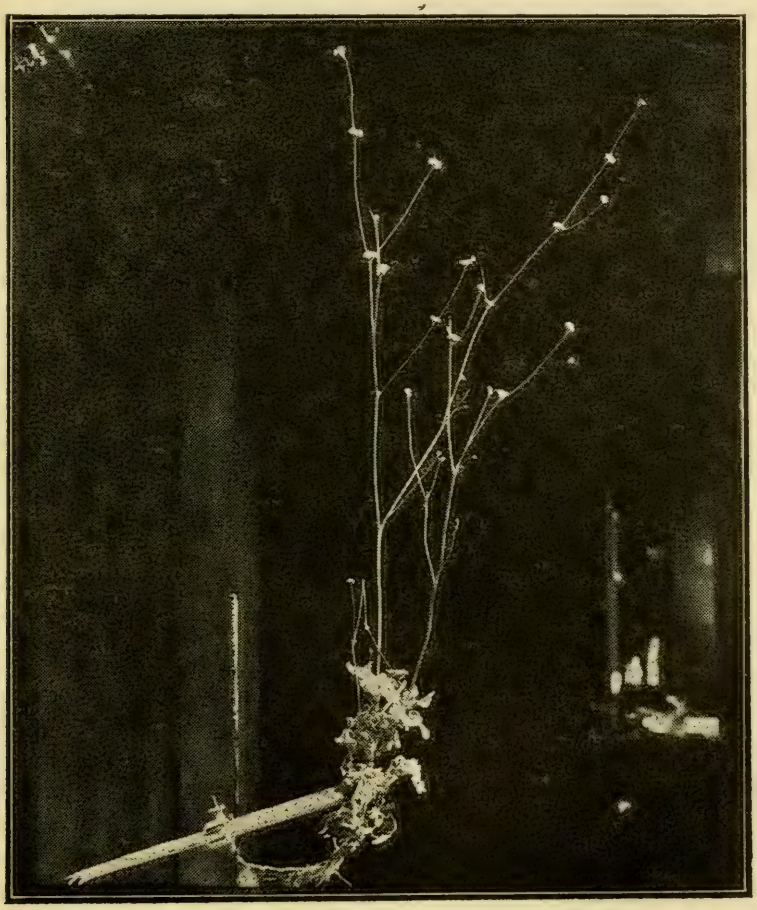


Figure 1. An entire plant of *Eriogonum nudum*, *ca.* 1/7 natural size.

* Lloyd ('16).

ground. From this there arises a long clavate-cylindrical internode ending in a group of crowded short internodes, bearing a corresponding number of small scale leaves. From this again spring usually three long internodes, these likewise ending in a series of crowded internodes. This is repeated till the final growth form is attained. From the crowded internodes eventually arise the flowers in tight clusters. We may therefor distinguish between short and long internodes—the latter being finally long, cylindrical and naked, and especially adapted for my work in view of the additional fact that they normally stand in all orientations, roughly at an angle of ca. 60 degrees with the horizontal.

Figure 2. Two pieces including growing terminal long internodes suitable for auxanometry. Slightly reduced.

Structure of the Growing Internode.—The internode which serves for the purposes of measurement is definitively a slender cylindrical shaft. The cortex, covered by a cuticle which becomes strong with maturity, is composed wholly of chlorenchyma. Stereome develops in the pericycle and in the outer zone of the medulla, and the advent of this cir-

cumstance marks the end of elongation. Within the zone of elongation, the cells are all thin walled with large vacuoles.

In a very young internode 13 mm. long, the zone of maximum elongation was found to be at the base. In one 60 mm. long, its maximum elongation took place about two-thirds the distance from the base to the apex, the entire zone being 35 to 40 mm. in extent. In an internode 199 mm. long, growth took place throughout a zone of 72 mm., 36% of the whole. Towards the end of the grand period of growth, elongation becomes more and more localized nearer and nearer the apex. In the final phase, growth is transverse, bringing the previously tapering shaft into cylindrical form.

It seems probable that the growing region becomes shortened during the major growth period of the afternoon (as Copeland, 1913, found in *Lagerstroemia*) when the extension of definitive mechanical tissues takes place. My own measurements, however, afforded contributory, but not conclusive evidence of this.

Like those of the cortex, the cells of the medulla are very thin walled in the growing zone, with thin protoplasmic utricles, and large vacuoles. They contain emulsoids which may be assumed to be pentoses in a very low concentration. They are dehydrated by alcohol and are rehydrated by water.

The behaviours of various internodes indicate that their dimensions have considerable relation to their growth rates. The more slender the part the relatively greater the evaporating surface, and the more suddenly the interior is affected by changes in the environment. This seems to account for the irregular growth during the day of the part furnishing the data of August 22nd—Sept. 3. The short-period fluctuations for this part are displayed in the table beyond.

Stomata.—It was found difficult to study the stomata and my results were more or less discordant. The *in situ* method (Lloyd, '13) could not be used on account of the size and shape of the internodes; and the alcohol fixation of stripped epidermis (Lloyd, '08) could be used only on plants other than the one under observation.

In the growing region of the long internode the stomata are very immature and are capable of only a very minor amount of movement. The cuticle is at this time but slightly developed, and we may infer that, though the transpiration rates may be low, cuticular transpiration takes a large share in it. It is a question whether the movements of stomata at a distance from the growing region have any close relation with the water balance of the growing part because of the rapid development of dense mechanical structures and of heavy cutinization amounting to a waxy coating, while the leaves have a very dense felt of trichomes on the lower, stomatal surface.

Whenever wilted stems were examined, the stomata were usually and for the most part closed, though as many as 5 to 10% were open. On a foggy day at 9 hr. the stomata on a long thin younger internode, but one well developed were for the most part open about 4 microns wide, while on an old internode they were open only 2-3 microns. At other times, when no wilting was evident, they were usually more or less open. At 14 hr. after three hours of sunlight, they were found in every condition. From repeated observations of this character, I have been able only to draw the rather meager conclusions that the stomata which are capable of movement are certainly open in the first half of the morning, that they close more or less when wilting occurs, but that they present no constant aspect otherwise. That cuticular transpiration is high in the growing region is an open question.

Method of growth measurement.—A special auxanometer, suitably encased, was devised for out-door registration, the lever giving a seven-fold amplification. The instrument was solidly placed on the north of the plant and a terminal internode occupying a north-south position was selected. This position was such as to allow the insolation to fall normally to the axis of the internode at all times. A special rigging allowed the internode to lie in a chamber so made and adjusted that the internode might lie exposed to normal conditions, or to be variously enclosed. It was possible to increase the amount of light impinging on the surface of the growing part by means of two mirrors, or to reduce the amount and at the same time to confine it to definite regions of the spectrum with blue[1] and red[2] screens. The humidity could be raised to saturation by closing the back of the chamber, closing it above with uviol[3] glass, and introducing moisture with an atomizer, using a temporary lining of filter paper. The construction of the chamber allowed these adjustments to be made quickly and without in the least disturbing the growing part. Connection with the registering lever was made with a celluloid saddle, which clasped the terminal bud without touching the internodal surface, and a light chain passing round a fixed pulley. The fixity of position of the base of the internode was maintained by fastening the top of the penultimate internode which had ceased growth to a rigging just outside the chamber. Small windows allowed the entrance of the top of this internode and the exit of the chain. The whole plant was fixed rigidly with stakes, and the entire system so weighted and adjusted that wind, rain (of which there was practically none) and other possible disturbing factors were excluded. The record, which was

[1] Wave lengths less than .510μ.

[2] Wave lengths to .610μ.

[3] All visible spectrum to .300μ.

received on a smoked drum, was perfectly clear cut and smooth, except when certain movements[1] caused sudden very slight deflections.

The character of the material and the effectiveness of the instrumentation were such as to achieve an interpretable record of growth rates of less than 0.1 mm. per hour, while the changes of rate following the imposition of experimental conditions were readily observable within a few minutes. Thus, on July 9, after cutting through the basal long internode, the shrinkage thereby induced began in five minutes. Earlier in the course of events, when normal shrinkage was being recorded. this was observed to cease at once on the removal of the basal leaves and positive growth in measurable values was recorded in 18 minutes.

July 9th. Beginning with 10.42 hour reading[2] (fig. 7).

Minutes:	60	15	45	60	60	Leaves cut	18	20	Basal internode	5	5	5	5	5	5	5
Growth:	20	5	-5	-15	-25	off at 13.42 hr.	5	10	entirely ampu- tated.	0	-20	-25	-13	-7	-6	0

Data obtained.—Complete growth records for fifty-five days giving the partial or for the greater part nearly entire growth history of six different internodes. It was of course not possible with the method used to begin a record before the internode had attained sufficient stature to permit the necessary instrumental adjustments to be made. The youngest one was 15 mm. in length at the beginning of the record. For the sake of economy the basic data are not given in their entirety. The accompanying graphs, however, summarize the whole array of data sufficiently for the purpose (figs. 3, 4). The records of growth on days of alternating sunshine and fog, and on which no experimental conditions were imposed have been omitted, except that their effect on the numbers expressing the average growth for the whole period of 53 days is included in the graphs of figs. 3 and 4. The complete records for the day period for days of continuous sunshine and of continuous fog, and for those on which responses to special experimental conditions occurred are given.

The numbers given in the tables which follow express in millimeters the movement of the writing arm of the recording lever, which amplified the growth movement sevenfold. These numbers are always used except when otherwise stated.

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[1] These movements were recorded as sharp serrations above the general course of the growth curve, the steep side of the tooth indicating a sudden shortening of the growing part, and the less steep side a slower recovery. They occurred with a periodicity of 20 to 30 per hour. An investigation of nutational movements showed that these also occurred, but with quite a different periodicity. It is purposed to give a fuller account of the movements in question at a later date.

[2] In the protocols which follow, the rates of growth are given as recorded instrumentally, and to obtain absolute values in mm. must be subjected to the correction x1/7.

The record on the drum was frequently checked by direct measurement of the growing part.

The environment.—The work was done at Carmel, California, at the Coastal Laboratory of the Carnegie Institution of Washington, chiefly during the summers of 1912 and 1916. Following is a brief exposition of the environmental conditions.

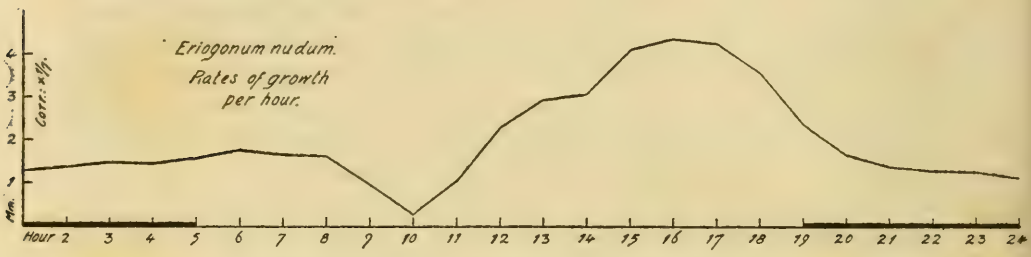

Figure 3. Average hour rates of growth for fifty-three days.

The outstanding feature of the summer climate is its monotony, and it is this that makes physiological studies in the field particularly instructive. Day after day during the summer the cycles of temperature, moisture and lighting repeat themselves with remarkable regularity. The disturbances which do occur are due chiefly to the movement of

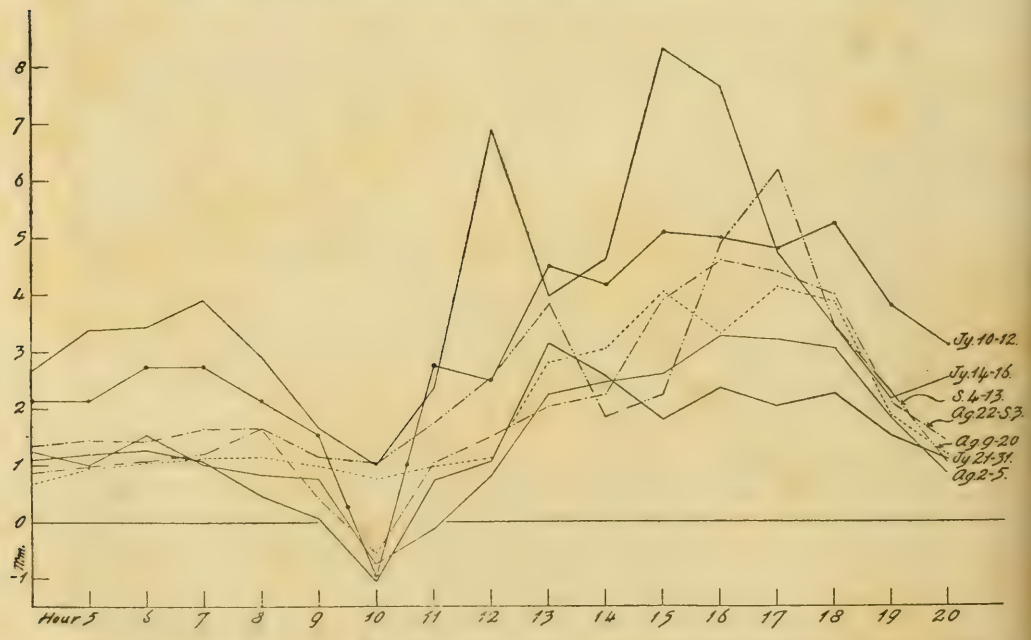

Figure 4. Average hour rates of growth of seven internodes for the periods indicated (see protocol, p. 242).

the ocean fog bank, which may rest over the coastal zone, sometimes as a "high fog" and occasionally as a "low fog". Even these disturbances, however, are scarcely ever erratic. If fog occurs, it usually persists for several days, during which the temperatures vary very closely within definite limits. If sunshine prevails, this usually persists for several days, with equally definite temperatures, which usually are but little higher than during the foggy periods.

As to temperatures in particular as recorded by a thermograph, during 70 days ending September 10th, 1916, the day maximum was

TABLE 1.

Typical evaporation, temperature and relative humidity data for Carmel, California, during the dry summer. Spherical porous cup (black) atmometers 1916 (see also Table 4).

Hour	8	9	10	11	12	13	14	15	16	17	18	Night
July 8												
Evap.	1.00	1.85	3.15	4.1	4.35	4.25	4.0	4.0	3.9	2.7	1.7	
R. H.	73	65	57	48	51	57	56	55	71	67	81	Dew
T.	61	68	72	74	70	69	71	72	66	63	60	
	Sunli	ght c	ontin	uous								
July 10												
Evap.	1.3	1.7	2.5	3.9	3.7	3.85	3.85	3.7	3.4	2.4	.9	
R. H.	73	.....	62	64	60	59	61	61	69	81	78	Low fog
T.	67	.....	70	69	70	69	68	69	62	59	59	
	Sunli	ght c	ontin	uous								
July 11												
Evap.	.....	1.2	2.25	3.8	3.8	3.8	3.5	2.8	2.0	1.0	....	
R. H.	.....	84	64	68	68	.....	72	....	....	84	....	Fog 21 hr.
T.	.....	59	70	66	66	.....	65	....	....	59	....	
	Sun t	ill 14	hr.						Hi	gh f	og 1	4 hr. on
July 14												
Evap.	.....	1.55	1.2	2.0		7.55	3.8	4.4	....	1.2	....	
R. H.	.....	79	74	65	.....	62	66	....	78	77	....	
T.	.....	59	60	69	.....	71	67	....	62	60	....	
	High	fog, s	un at	11.3	o					Hi	gh f	og 14 hr. on
July 15												
Evap.	.....	.....	2.7	4.0	3.0	3.0	3.0	3.5		5.2	1.0	
R. H.	.....	74	73	65	67	67	68	71	....	78	87	Dew 23 hr.
T.	.....	65	68	69	68	69	71	68	....	63	59	
	Occas	ional	sun	High	fog							
		9.30		1	1.00		Sun	15.2	o till	16.2	o	

between 78 and 80 degrees on four days, at 75 degrees on six days, 70 to 72 on seven days. The rest of the time it never rose to 70 nor fell below 60, save on one day only, August 4th, when it was 59 degrees. For the period July 30th to August 17th, the maximum was 71, the minimum 62, and on four successive days it was exactly 68. The night temperatures ranged between 42 and 54, on 31 out of 70 going below 50. The night growth rates were always very low, the maximum recorded being rather less than 0.4 mm. per hour.

Humidity: evaporation (fig. 9).—The humidity cycle is similarly regular. The dew point is approached or reached every night. After sunrise the fall in relative humidity proceeds steadily till the 11 hour after which for about four hours it remains fairly steady, usually lowering somewhat. After the 15 or 16 hour it rises again. The course is paralleled in the evaporation rates, which stand at zero during the night usually until the 7 hour proceeding thereafter to a rate near the maximum at 11 hour. The records of several days are here given as examples. A day such as July 8th means a slight movement of air from inland; one such as July 14th that this air movement is not sufficiently deep to keep the cooler air of the ocean from invading the coastal strip of land, at a high altitude and carrying with it the thin edge of the ocean fog bank. Days of low fog are due to the surface invasion of the ocean fog bank, and during such the lower day temperatures occur. Only two such occurred during the period of observation, and, as the parts whose growth was being recorded were near the limit of growth on these days, only low absolute values were obtained and these therefor cannot be used for comparison.

The total illumination on the plant surface on days during which high fog prevails is little less than otherwise. The fog is frequently so thin that the direct heat of the sun may be felt on the face, and weak shadows are cast. On such days the temperatures are little if at all inferior to those of sunny days. The chiefly variable factor therefor is the light as direct insolation when, on partly foggy days, it may have all the range of values from that through heavy high fog to direct sunlight.

There is most generally little wind and no rain. During the night "weeping fog" or mist sometimes wets the surface of the ground beneath the trees, and very occasionally may wet the surface generally.

The plants which afforded the material grew on a gentle slope with southern exposure and were exposed during the whole day to full insolation except till about 8 hour, and of course when fog prevailed till the late afternoon, when partial tree shade fell on them, as in the early morning.

The soil temperatures of this situation were very even, ranging during the summer at 18 cm. depth between 21 degrees and 23 degrees C. The maximum is reached late in the afternoon, not earlier than 20 hour, and is due to transmission of heat from the upper to the deeper layers. The 18 cm. layer lags about 4-5 hours behind the 13 cm. layer.

The soil is sand with a very slight admixture of humus; is, in fact that of an old sand dune.

Daily periodicity of growth.—A generalized conception of the daily growth cycle of *Eriogonum nudum* under the conditions described is conveyed by the graphs which exhibit the average hour rates for several internodes for their entire growth periods (fig. 4) and for the whole period of observation, 53 days (fig. 3).

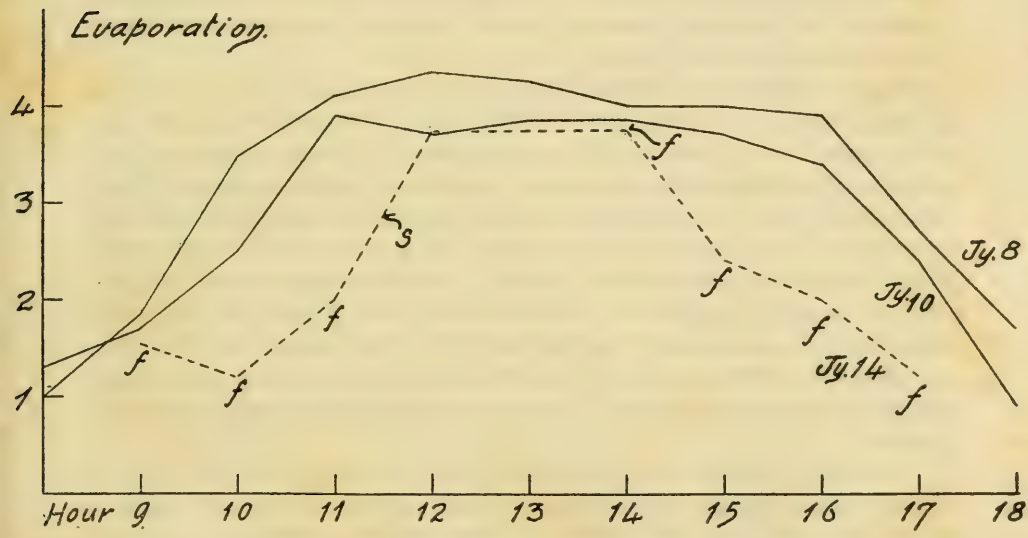

Figure 5. Hour rates of evaporation: *s*, sunlight; *f*, high fog.

Regarding particularly the latter it is seen that during the night the average growth rate is somewhat less than .2 mm. Beginning with the 4 hour there is a slight increase of rate till 6 or 7 hour after which there is a slight decrease in rate. After 8 hour there is a rapid drop in rate to zero, or practically so. At 10 hour there occurs an equally rapid rise in rate, culminating at 16-17 hour when the rate attained reaches a value approximately four times the night rate. After the 17 hour the rate falls again till the night value is reached at about 21 hour (Fig. 3).

The critical features of the cycle are (1) the amount and constancy of the night values; (2) a usual but not invariable increase in rates after

dawn till 7 or 8 hours, (3) the reduction of rates till about 10 hour, (4) the rapid increase thereafter till the 15 or 16 hours, and (5) the final drop to the night rate. The absolute values for any day depend largely on the degree of development already attained by the internode. Obviously, when it has almost completed its growth, the amount of growth relative to the extent of the growth zone may be as great as before although in absolute terms it is much reduced. Having due regard to this fact, however, the records show that *no single day out of* 53 *for which complete hourly records were obtained failed to display this behaviour.* It will, however, be pertinent and necessary to point out the departures from the average behaviour. Their extent is shown sufficiently well by the graphs in figure 4, which are the average hourly rates for the several internodes treated separately. The following statements are based on a study of all the data, some of which, however, as above said, have been omitted from this paper.

Night growth rates: There was almost invariably a gradual drop in rate during the hours preceding midnight, during which period also there was a reduction in air temperatures. Between midnight and 4 hour the rate was quite constant, having an absolute value of .1 to .2 mm. per hour. A maximum rate of .4 mm. per hour was observed once, while, in internodes approaching their limit of growth, there might be practical cessation of growth. The behaviour after midnight did not seem to follow air temperatures alone, since the minimum temperatures were usually reached at from 4 to 6 hour. In only four instances was minimum growth recorded for 6 hour, while the minimum temperatures occurred at this hour 26 times during the period of observation.

From 4 to 6 hour, the period of dawn, there was still b it little growth, there having been recorded a slight increase of rate on half the days of observation, the rate on other occasions having remained constant except on four days when in long internodes there was a slight fall in rate. This occurred on mornings when the temperatures rose rapidly, but did not involve an absolute change of rate of more than .2 mm. and was followed by rise for a brief peroid.

After the 6 hour the rate remained either constant, or more usually rose somewhat, the rate increase being somewhat greater on foggy days. On about 25% of the days it fell. That is to say, the period of shrinkage might set in as early as 6 hour, but the turning point was usually later, generally at 7 hour; and it might be as late as 9 hour. The maximum rate, in 96% of the instances was not more than double the minimum night rate. In one instance a rate thrice, and in another, nearly five times that of the minimum night rate was attained (on S. 4). The

growth of this day was quite exceptional. The part was quite thick and young, 31 mm. long, and was subjected to high temperatures. Instead of the usual morning period of shrinkage there were three periods of reduced growth rates, while the period of major growth was postponed till late in the afternoon (table 3).

The period following the critical hour of maximum early morning growth, which falls, as above said, on any hour from 6 to 9, but which usually occurs at 7 to 8, is one of either much reduced growth rate, or net shrinkage. The latter condition occurred on 31 of 53 days.

The maximum value for this shrinkage (measured 8-10 hours on August 30th) during the period was 0.9 mm. the internode having been 88 mm. long at the beginning of the day's growth. It was the observation of this behaviour in 1912 that furnished the impetus to the work, at which time it was noted that the terminal internodes frequently wilted sufficiently to become pendulous (Lloyd, '12). The direct measurement of several long internodes discovered either cessation of growth, or, when wilting was evident, maximum shrinkages of 1-1.5 mm. being about 2 to 3 per cent. on the length of the growing portion. It was noted that at the time the auxanometer was registering shrinkage, the growing internodes of nearby plants showed wilting, though of course the part serving for measurement did not alter its form except longitudinally because of the pull—of about 3 grams—of the lever. Although the plants studied in 1916 showed this behaviour usually between 8 and 10 hour, the measurements of 1912 indicate that this is not always the case but is modified by various surrounding conditions. The plants studied in 1912 were growing in another place and were shaded by trees during the first half of the morning. Recurring to the conditions of 1916 on days of continuous sunshine (table 3; fig. 6) the shrinkage commenced at about the same time as on foggy days but advanced to absolute values of about twice those of foggy days. The period of slackened growth was, however, generally more prolonged on foggy days, on which also there were lower recovery rates between 10 and 14 hours (graph 3, fig. 6). When the temperatures were abnormally high, as when the part was enchambered behind uviol glass, the shrinkage was induced about an hour earlier (at 9 hour) and proceeded to absolute values slightly greater than those for sunny days with normal temperatures. With higher temperatures and sunlight the greater part of the shrinkage was more usually accomplished during the earlier phase of the process, while under normal temperatures the shrinkage became accelerated during the later phase as frequently as not.

The rise in growth rates at the conclusion of the period of slackening or shrinkage was invariably shown. On days of continuous sunshine

the maximum absolute rates were reached usually as late as 17 to 19 hour. The evidence indicates rather clearly, however, that another, lower maximum is previously reached, namely at about the 14 hour. During the period between 14 and 17 hour a second slackening of rate occurs. This behaviour is discoverable on days of sunshine at both normal and supranormal temperatures (table 3; fig. 6). It is to be noticed furthermore that the acceleration of growth after 10 hour is greater than on foggy days, and greater at supranormal than at normal temperatures on sunny days. It seems therefor that the accelleration of rate is proportional to the amount of shrinkage, and that the time at which it

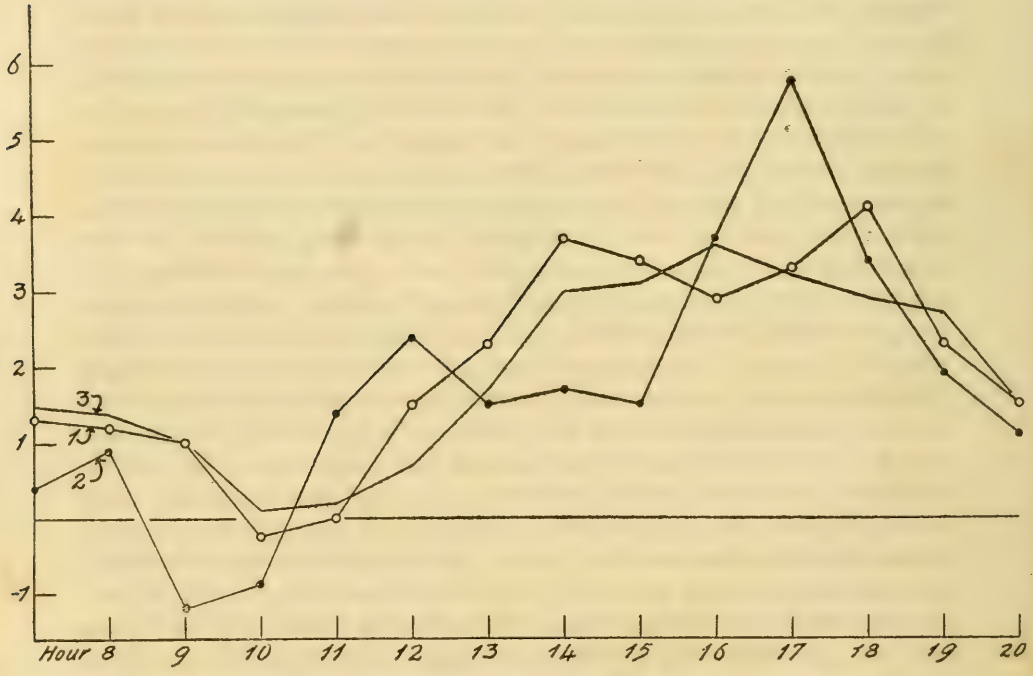

Figure 6. Average hour rates of growth for days of continuous sunshine (curve 1), for similar days with high temperatures (curve 2), and for days of continuous high fog (curve 3), (Table 1).

occurs fluctuates with the time of shrinkage—the earlier the latter, the earlier the recovery. On foggy days a single maximum at 16 hour is approached steadily, and there is no evidence that an afternoon period of slackened growth occurs, as on sunny days. The absolute high rate values on sunny days are uniformly somewhat greater than on foggy days, except when higher temperatures prevail when they are considerably lower during the period following the first maximum.

As maturity of the internode approaches, the zone of elongation becomes shorter and the absolute values of both shrinkage and growth

becomes less. Both the minima and maxima of the march fall at the same hours, and the behaviour is attributable to factors identical with those operative for internodes during the period of maximum growth (cf. MacDougal, 1918, p. 59).

These behaviours are I believe understandable when the conditions affecting transpiration are considered. The closure of the stomata which occurs on wilting permits the increase in the net water content of the growing part, and this in turn, the assumption of restitution which, as we have seen, is accomplished rapidly on sunny days, that is, when the most complete wilting and stomatal closure have occurred. But on such days the period of high evaporation persists till the 15 or 16 hour so that, although the part has displayed an ample recovery, there ensues, because of the probable opening more or less of the stomata for a second time, for which I have some evidence, a second slackening of growth rates, not very pronounced, to be sure, but evident. It consists with this explanation that the second maximum—and this time the greater—is only reached after the evaporation rate has begun to decline; and further that on foggy days the maximum is reached earlier if more gradually and steadily, since on these days the evaporation rates are lower and decline earlier (fig. 5). The data for separate days (table 3) show that on these there was almost invariably a single maximum only, albeit this may fall as early as 13 hour or as late as 17 hour, variation in behaviour which would doubtless correlate with evaporation conditions. It is however of importance to point out that the absolute values for the earlier maximum on sunny days are frequently as high as those of the maximum for foggy days, and similar values may be reached on both sunny and foggy days even at midday, a fact which contravenes the view that light as such within the limits of availability, acts inhibitorily.

So far as the data serve to indicate, there seemed to be a tendency for the maximum to be reached later in the afternoon as the season advanced. This tendency may have depended on the decrease of soil moisture which without any doubt occurs. It might be argued that a concomitant greater daily shrinkage should also manifest itself. Since this is not evident, however, it may be inferred that during the morning hours the water accumulated in the plant during the night is lost, while the subsequent behaviour, later in the afternoon, involves an immediate draft on the soil moisture. It is most significant that rapid growth rates may be assumed during the period of maximum insolation.

Relative amount of growth in day and night (table 2; figs. 7, 8).—It will be seen from the above that the maximum day rates of growth are much higher than the maximum night rates. Furthermore, in spite of the

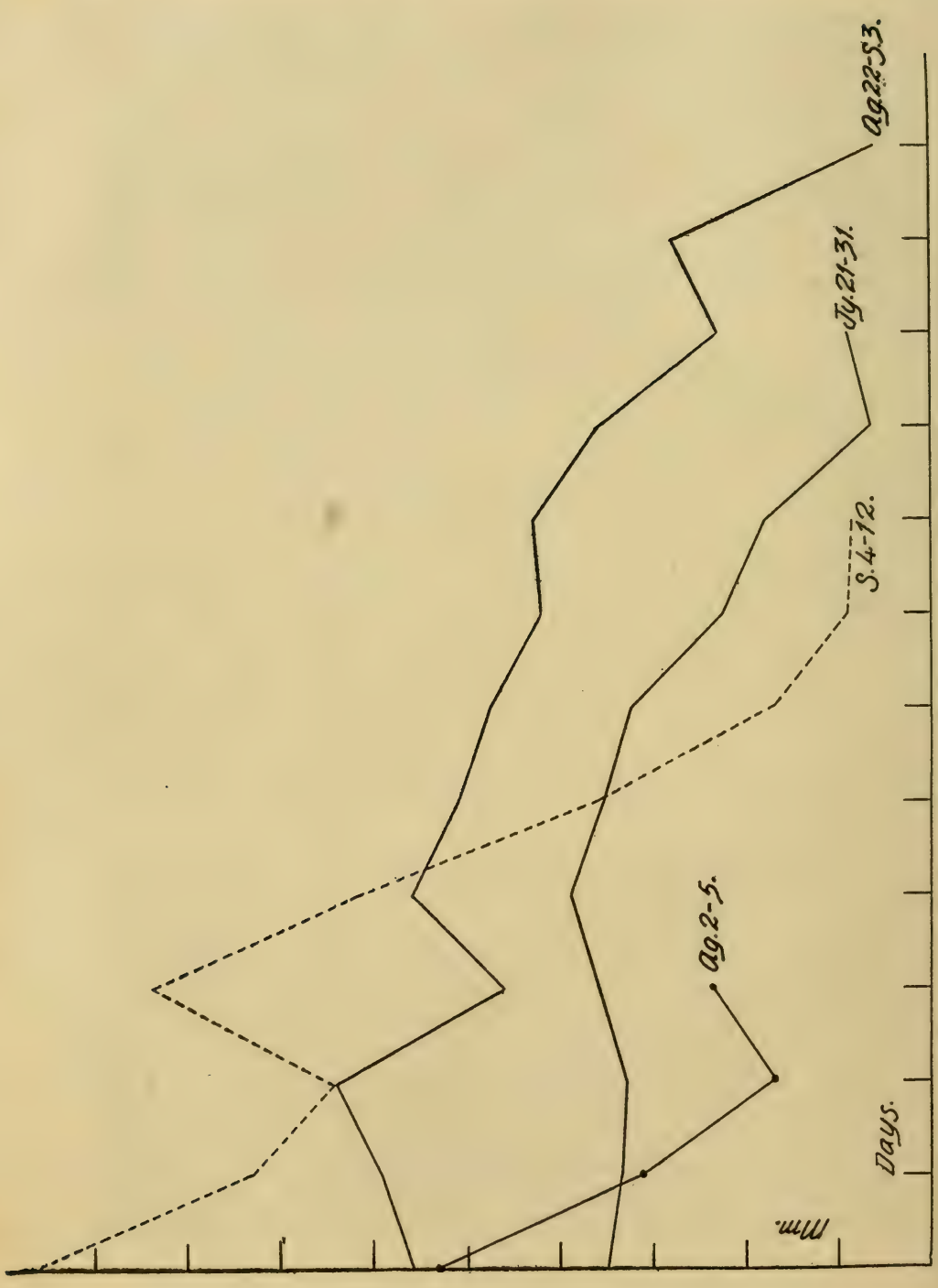

Figure 7 Total growth per day (daylight hours only) of four internodes during the periods indicated.

reduction of rate or even shrinkage during the morning, the total amount of growth accomplished during the hours of daylight is far in excess for equal periods than that for the hours of darkness (table 2). The ratio of day growth per hour to that of the night was found to be 1.7, 2.6, 3.4, 2 and 4 for five different internodes (fig. 8).

TABLE 2.

Total growth of various internodes for each day of record (*a*) and the total growth for the 14 hours of daylight each day, (*b*) in mm. (Figs. 7, 8).

Part no.	Period	Length		Daily accretions Day: 1	2	3	4	5	6	7	8	9	10	11	12 13	Totals
1	Jy. 21-31	88	*a*	5.1	6.2	5.9	6.5	5.9	5.2	4.7	3.0	2.3	0.8	1.1	.....	46.7
			b	3.6	3.4	3.3	3.6	3.9	3.5	3.3	2.2	1.8	0.7	0.9	.....	30.2
2	Ag. 2-5	60	*a*	6.9	4.2	2.9	3.1	...	...	...	...	...	...	...	.....	17.1
			b	5.3	3.1	1.7	2.3	...	...	...	...	...	...	...	.....	12.4
3	Ag. 9-20	15	*a*	3.6	5.5	9.5	8.0	5.5	6.2	8.3	8.3	5.6	3.5	1.9	1.3...	67.2
			b	3.1	4.0	7.1	6.4	3.9	4.3	6.2	6.2	4.6	3.0	1.7	1.2...	51.7
4	Ag. 22-S. 3	24	*a*	7.3	7.9	8.9	6.5	8.6	7.7	7.4	6.6	6.7	5.2	3.4	3.50.8	80.5
			b	5.6	5.9	6.4	4.6	5.7	5.1	4.8	4.2	4.5	3.6	2.3	2.80.6	56.1
5	S. 4-12	31	*a*	11.4	9.0	8.1	10.1	7.7	4.9	2.4	1.2	1.1	...	...	.....	55.9
			b	9.6	7.3	6.4	8.4	6.2	3.6	1.7	0.9	0.9	...	...	.....	45.0

NOTE—The growth record for Ag. 6-8 incl. was not reduced since the part was almost at its limit of growth, the average hourly rate for the whole period being 0.07 mm.

These ratios are for total net growths merely. As may be seen in table 2, the possible amounts of growth during single hours may in some instances be expressed by a ratio as high as 8 or even 12 (July 31st; night rate 0.2, day 2.5) when a part is near its growth limit. Then indeed growth may cease altogether during the night and assume a relatively high rate for a short period during afternoon.

The comparative rates and amounts of growth on sunny and foggy days are still more pertinent and interesting, since, if direct sunlight is conceived as acting inhibitorily it would seem logical to expect a greater growth on days of high fog, in view of the favourable temperatures which prevail. Table 3 shows that the higher rates for sunny days are frequently higher than for foggy days—one hour-rate (that of August 24th, 15 hour) being very exceptional and notably higher than any others. Since however the rates on sunny days fall so late, it is evidently

TABLE 3.

Growth rates on days on which no special experimental conditions were imposed. (Fig. 6).

	Hour:	7	8	9	10	11	12	13	14	15	16	17	18	19	20	24
Days of continuous sunlight	Jy. 21	10	10	10	−8	−22	−5	10	40	33	17	36	**38**	38	24	16
	" 22	16	14	5	5	−25	4	11	**53**	33	30	2	28	50	35	13
	" 24	20	15	5	−10	−15	0	20	35	40	30	**45**	24	23	20	20
	" 27	10	10	20	10	20	15	15	**50**	35	10	20	15	25	10	4
	" 28	10	10	3	7	−25	15	15	**35**	25	15	10	20	10	10	3
	Ag. 2	12	10	20	−15	−8	7	13	40	40	60	70	**75**	25	10	7
	" 11	10	5	12	3	20	50	50	62	53	33	64	**70**	30	19	19
	" 17[1]	14	14	10	10	5	10	30	35	35	35	40	**50**	20	10	2
	" 18[2]	3	3	5	−10	13	22	22	23	20	23	27	**43**	12	10	2
	" 19[3]	2	2	0	−12	0	10	14	13	17	**26**	24	18	2	2	1
	" 23	30	30	20	0	37	23	50	20	40	37	28	**65**	23	20	14
Sunny days temperatures raised with uviol glass	Ag. 24	20	20	11	−12	6	10	34	56	**145**[7]	45	45	40	22	14	14
	" 31	7	4	−31	−7	22	**26**	19	20	10	15	**75**	50	27	18	6
	S. 1[4]	5	3	−21	−17	12	**13**	5	**15**	10	30	**40**	40	17	8	6
	" 2[4]	4	4	−9	−22	11	7	**14**	14	12	63	**69**	27	5	5	5
	" 3[4]	1	2	6	− 8	0	0	−2	5	13	**15**	15	15	..	..	..
	" 4[5]	20	47	30	59	41	**57**	58	35	50	82	**97**	51	29	16	10
	" 8	5	20	−15	10	25	**65**	40	30	30	60	**90**	40	25	15	10
Foggy days (high fog)	Jy. 26	20	14	4	3	−8	5	5	10	15	30	**40**	25	40	30	25
	Ag. 3[6]	11	7	2	−15	8	10	**50**	22	22	30	24	16	15	10	6
	" 4	10	8	4	3	3	5	10	**17**	10	13	12	15	..	7	4
	" 5	7	8	4	−4	−8	3	17	20	26	**28**	22	16	15	6	7
	" 10	15	17	8	15	10	10	10	15	**40**	25	40	40	25	15	13
	" 22	16	19	17	18	10	18	15	**55**	50	50	37	38	38	17	10
	" 28	22	23	30	3	−2	−3	−2	45	30	**65**	40	35	27	18	17

A day of low fog with sun for one hour (from 9 till 10 hr.)
Part near its limit of growth.

Jy. 19	3	10	−1	−2	0	−6	8	5	20	13	20

[1] On Aug. 17 a tin reflector remained behind the part for the day. Temp.: 86–90; 17 hr. 76.

[2] Aug. 18. Part approaching its limit of growth. Temp.: 14 hr. 97; 18 hr. 57.

[3] Aug. 19. Growth nearly complete; cutinization advanced. Temp.: 13 hr. 86; 17 hr. 64.

[4] Sept. 1, 2 and 3 include the growth rates for a single internode near its limit of growth.

[5] Sept. 4. A young internode 31 mm. long, subjected to high temperatures; 8.40 hr. 87; 9.20, 99; 12, 105; 14, 106; 14.40, 102; 16.15, 86; 16.40, 74; 17, 77; 20, 55. Growth from 7.40 to 7.55 and from 8.30 to 8.55 = 0.

[6] Aug. 3, 4 and 5. Part near its limit of growth.

[7] Aug. 24. A very exceptional reading, which for statistical purposes has been taken as 50. Uviol glass from 11.35 on. Temp. 104 at 12; 106 at 13; 68 at 15. High fog 14.30.

more to the point to compare rates for the same hour for different days. For the 12, 13 and 14 hours we find generally higher rates for sunny even though the maximum is no higher except than for foggy days with

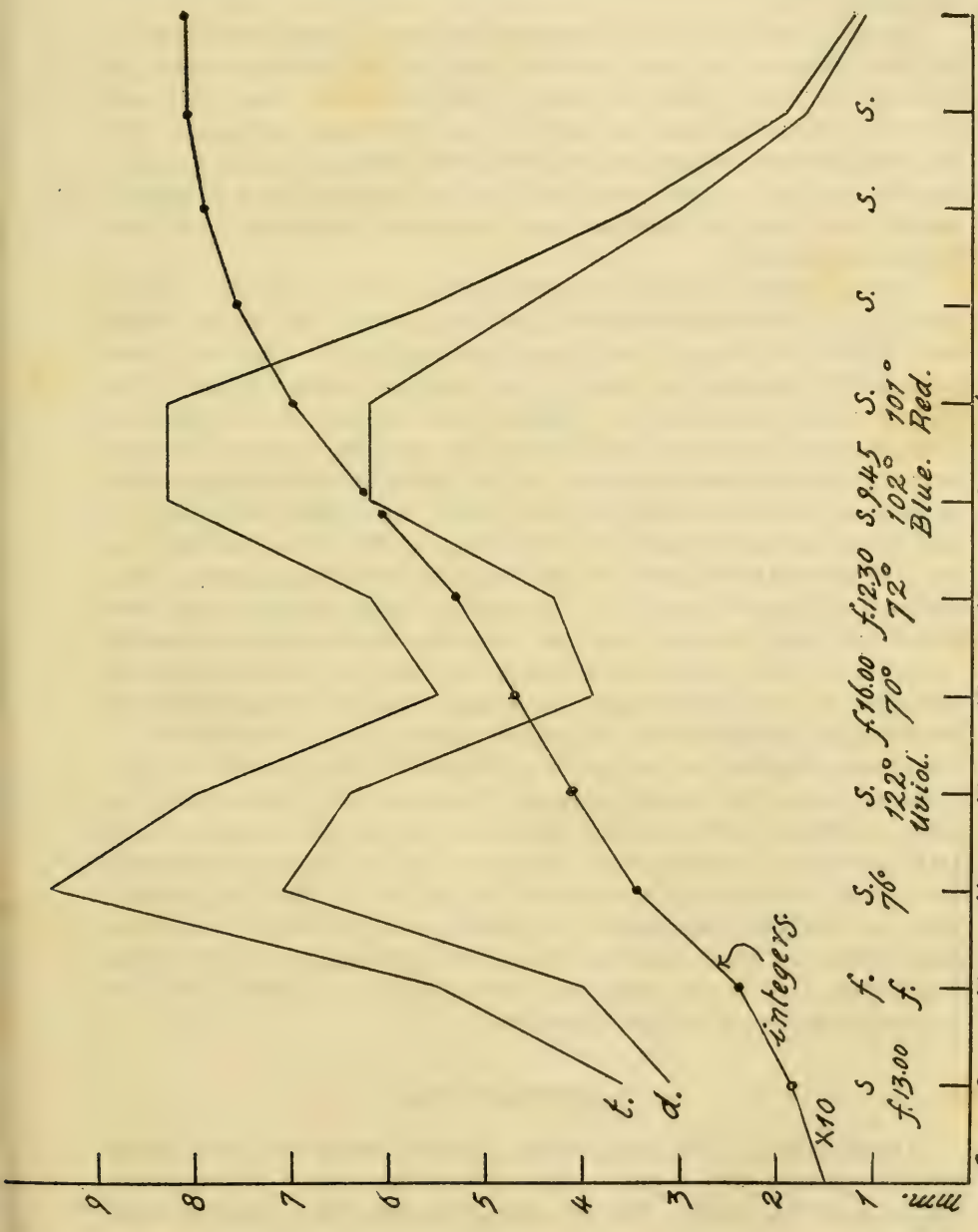

Figure 8. Total growth per day (*t*) and for the daylight hours only (*d*) of a single internode; *s* sunlight; *f*, high fog; the maximum temperatures are indicated.

higher temperatures. For the following period of two hours the balance is the other way, to change again later. At the hours therefore of maximum insolation the absolute hour rates are on the whole higher on sunny days.

Again, if we take the total amounts of growth during the hours of daylight following the last minimum rate, for the different days, we find that for sunny days the average total growth is 4 mm., for such days with higher temperatures, 4.6 mm., and for foggy days 4 mm. By discarding extreme figures we find but little difference in the final expression, so that we may conclude that the general result of growth performance does not indicate less favourable conditions to be due merely to sunshine.

The record for August 8th to 20th bears out this conclusion. These were days of continuous sunshine save for fog after the critical hours, as indicated in figure 8, on August 13th and 14th. The maximum total growth occurred on a day of continuous sunshine (August 11th) with moderate temperatures. August 12th, 15 and 16 were days of equal amounts of growth. On the 12th the part was subjected to high temperatures of a closed chamber, and the light was intensified by means of mirrors, the window being of uviol glass. Somewhat lower, but still high temperatures obtained on the 15th and 16th, with blue light on the 15th and red on the 16th. Consonant with the high temperatures the higher daily growth rates (*e.g.*, as compared with August 11th) were delayed till after the noon hour, and this delay was especially noticeable on the 12th, when the temperatures of the chamber reached, and were sustained at, abnormally high quantities. Indeed, the possibility of interpreting the depression of growth on this day as due directly to the intense illumination as such is admitted, but is excluded by other evidence, as *e.g.*, the sudden increase of rate to a high value under the same conditions of illumination merely by raising the humidity (July 16th, 17th); and the high rates on August 24th, the increase beginning at 10 hour and reaching a maximum of 15 hour. When one reflects that the conditions supplied to the growing part on August 12th were most stringent—much more so than would ever occur in the habitat where these experiments were done—it is a matter of surprise that the rates of growth were as high as recorded.

EXPERIMENTAL.

Transpiration.—The transpiration rates of two plants were determined synchronously, together with evaporation rates. Of the plants, one retained its rosette of leaves; from the other they were removed.

The leaves are ovate, strongly cutinized above and clothed with a dense white felt beneath. The whole plant is distinctly xerophytic in character. The course of transpiration for two days for the plant which bore its leaves is shown in fig. 9. On the first day (July 12th), which was cool and foggy (max. temp. 63) the transpiration followed a course almost

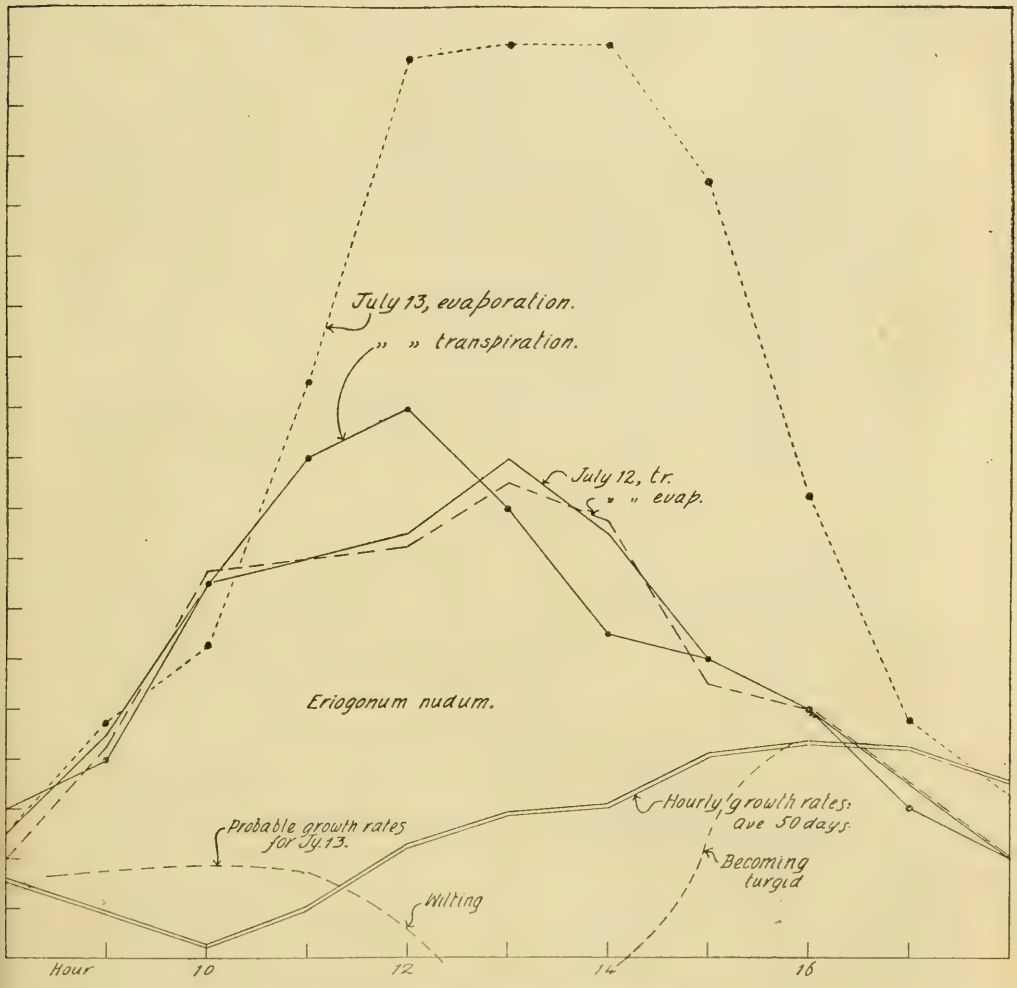

Figure 9. Growth, transpiration and evaporation.

identical with that of evaporation, the ratio evaporation to transpiration for the period 6-18 hour being 27 cu. cm. per 100 sq. cm. (cylindrical porous cup) to 4.1 cu. cm. per 100 sq. cm. plant surface, or 6.5 to 1. On the following day there was a light and intermittent fog in the morning, gradually becoming brightly sunny at 10 hour. Up to this

hour the course of transpiration followed in general that of evaporation, the former increasing somewhat more rapidly. With the clearing of the fog the evaporation increased during two hours to a three-fold rate, the transpiration meanwhile attaining its maximum. The form of the graph shows that after 10 hour there was a gradual checking of transpiration and a decided falling off after noon. At the 11 hour all the terminal internodes on both plants were turgid, but, while they remained so in the leafless plant, they showed complete wilting by the 13 hour in the other. In this case, these two or three hours previous to 13 hour were the period of growth cessation and shrinkage, recovery from which was complete by 16 hour. Plants growing under their normal conditions (but not where growth records were made) showed wilting in similar manner, with synchronous recovery. On days when sunshine obtained the evaporation rate attained by 9 hour was equal to that of the 11 hour on July 13th, under which circumstances the wilting would doubtless have fallen earlier. It seems therefore obvious that the checking of growth, culminating in shrinkage when the conditions are stringent enough, is the result of net water loss by the plant (Livingston and Brown, '12; Lloyd, '12*a*, '13) produced primarily by the evaporation conditions.

TABLE 4.

Transpiration, evaporation, etc. July 12th, 13th, 1912.

Cylindrical black porous cup, area 48 sq. cm. (fig. 6). Situation: a steep eastern slope at Coastal Laboratory.

Hour:	7	8	9	10	11	12	13	14	15	16	17	18
July 12												
Evap.	.....	0.4	0.85	1.55	1.6	1.65	1.9	1.75	1.1	1.0	0.7	0.4
R. H.%	.....	.....	79	.....	67	57	69	.....	.....	75	84	.....
Temp.	.....	.....	59	.....	63	62	63	.....	.....	61	57	.....
Transp.	.....	.25	.45	.75	.80	.85	1.0	.85	.60	.50	.35	.20
	High fog, sun	at 9	for 15	min.			High	fog,	dense	after 11	hr.	
July 13												
Evap.	0.35	0.5	.95	1.25	2.3	3.6	3.65	3.65	3.1	1.85	0.95	0.65
R. H.%	81	75	74	60	57	.....	59	56	.....	67	.....	.....
Temp.	56	58	59	67	69	.....	69	69	.....	63	.....	.....
Transp.	0.2	0.3	0.4	.75	1.00	1.1	0.90	0.65	0.6	0.5	0.3	0.2
Fog.	Sun at 10 hr.		Turgid.		Wilting at 12.		Shade (of trees) 15.20.			Becoming turgid at 15 hr.		

Evaporation for a fog day, Jy. 8

0.0	0.2	0.35	1.1	1.45	1.7	2.15	1.6	1.15	1.2	0.75	0.6

Total evaporation for a sunny day, July 13th, 22.65; for a foggy day, July 8th, 12.25.

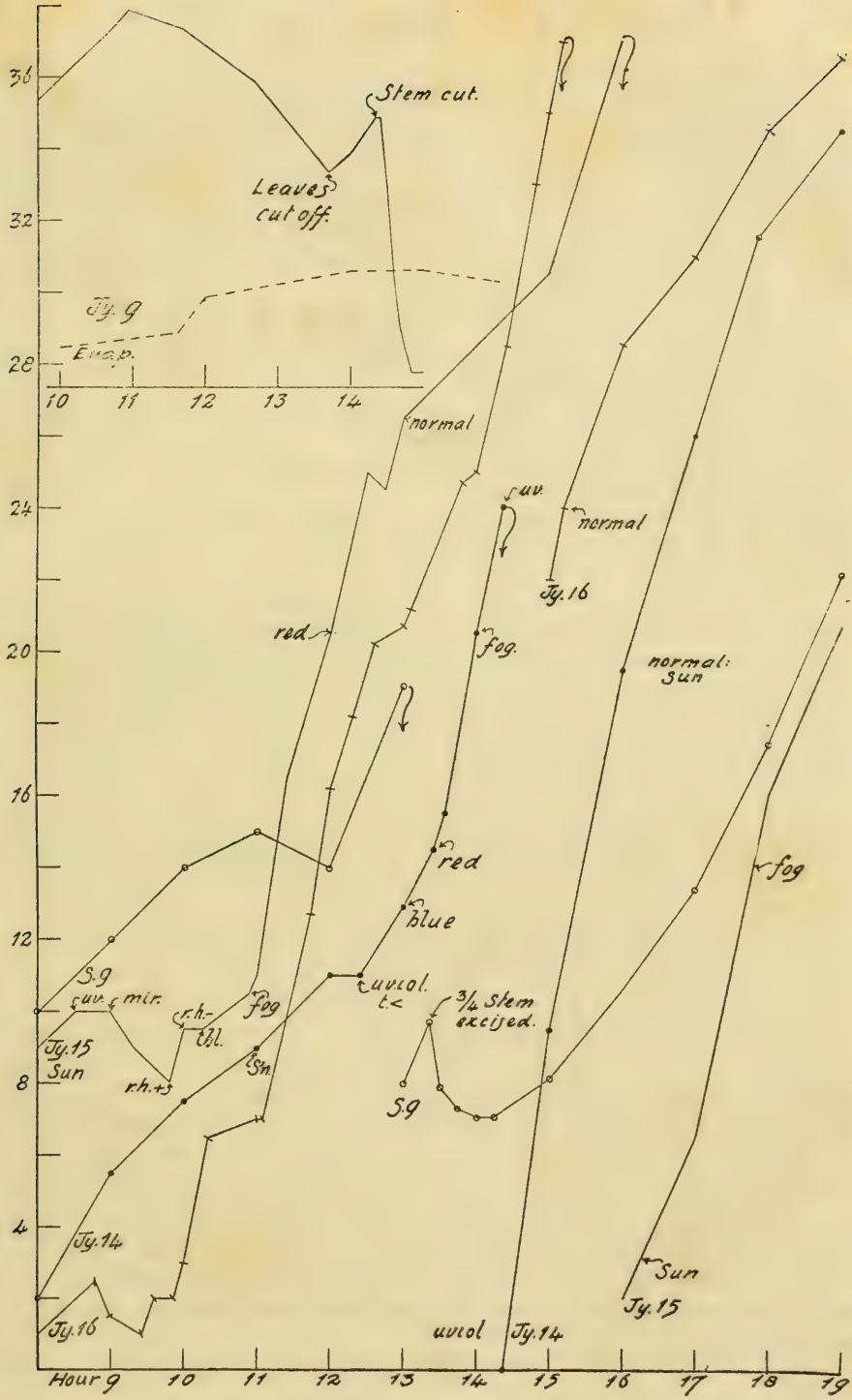

Figure 10. Growth under various experimental conditions; *uv*, uviol glass screen; other screens are indicated: *bl*, blue; *r.h.*, relative humidity.

The effect of foliage, as indicated above, is to deflect the water proceeding from the roots, thus menacing the supply to the upper parts by producing negative pressure in the stems. If so, it was argued that the amputation of the leaves at the moment when cessation of growth becomes manifest should result in increased growth rates. This was the case, as indicated by the following changes in rates:

Jy. 9. Leaves cut off at 13.43 hr. From -.3 to .2 mm. per hour (in 20′) to .4 mm. (in 20′).

Jy. 10, beginning with 7 hr. reading:

Min.:	60	48	27	30	35	20	Leaves removed	20	30	30	60
Rate:	42	25	-29	36	26	-60	at 9.40 hr.	30	10	50	40

or from -.9 mm. per hour (in 20′) to .4 mm. (for 20′).

Jy. 16, beginning with 9 hr. reading:

Min.:	12	25	10	16	Leaves	10	19
Rate:	-25	-7	30	11	removed	42	111

or, from .1 mm. to .6 mm. per hour in 10′, and then to 1.5 mm. in 19′.

Aug. 13, beginning with 7 hr. reading:

Min.:	60	60	60	60	60	60	60	40	Leaves removed	20	60	60
Rate:	15	10	10	0	-10	5	15	18	at 13.40	69	45	60

or from .25 mm. to 1.0 mm. per hour.

The amputations were done when the amount and direction of growth were sufficiently apparent in the behaviour of the writing point of the lever that any result of the experiment would be at once apparent. Within a few minutes in all cases it could be seen that the alteration of direction had taken place practically at the moment of amputation. The fact that such was the case is of more importance than the actual rate values for a period previous to and following the amputations.

The opposite result, as one would expect, follows the reduction of the vascular tissue of the chief stem. The effect is, however, somewhat unexpectedly transient. On September 9th, at the close of the first hour of active growth, at 13 hour the tissues of the basal internode were cut through sufficiently to reduce the amount of vascular tissue to one fourth. Growth was at once affected (September 9th, fig. 11) there being a total shrinkage of about 0.4 mm. within an hour, after which the growth rates characteristic of the time of the day were resumed. One may recall that the excision of tissues in this manner is not effective in bringing about abscission, even though it is clear that the negative water tensions in the plant are certainly known to be a cause of it (Lloyd, '14, '16*a*).

Just as increase of growth rates may be induced by the amputation of the leaves, so also by the interposition of shade, not, as will be shown, as a direct result of the reduction of light, but by lowering the rate of evaporation and of transpiration. On days of bright sunshine (July 6th, 8th, 11th) when the rates were low, these rose to marked positive values when shade was supplied, and fell again when, after an hour, the shade was removed.

EFFECT OF SHADE.

Jy. 6. Beginning with 8 hr. reading. Sunlight all day:

Min.:	60	60	25	10	5	12	8	60	30	60	plant shaded
Rate:	45	0	0	-60	0	-75	0	5	40	0	12 hr.
	60	shade removed	60	60	60	60					
	50	13 hr.	35	30	25	20					

Jy. 8. Beginning with 8 hr. reading. Sunlight all day:

Min.:	60	60	60	60	plant shaded		5	55	shade removed		60	60	60
Rate:	45	-20	-45	-10	11 hr.		0	93	12 hr.		-15	0	15
Evap'n:	1.0	1.85	3.15	4.1			2.85	(shade)	4.25	4.00	4.00		
Temp.:	61		72	74.5	..		70		69.5	71	72		
Min.:	60	60	60	60	60	60							
Rate:	90	65	115	55	50	42							
Evap'n:	3.9	2.7	1.7										
Temp.:	66	63	60.5	55									

Jy. 11. Beginning with 8 hr. reading. Sunlight till 14 hr. after which high fog.

Min.:	43	77	23	37	60	60	32	plant shaded	38	39	shade removed	
Rate:	49	12	13	-37	30	32	24	12.32	40	46	13.39	
Min.:	21	60	60	60	60	60	60					
Rate:	43	55	50	40	50	37	20					

That this is not a direct light effect was proved by the occurrence of similar changes in growth rates during continuous brilliant insolation, by means of raising the humidity within the chamber. To this end, the chamber was closed with a sheet of uviol glass. The back of the chamber was closed also, and the mirrors were placed behind the internode. The temperature rose to a high value within the chamber. This was done on six occasions. The data indicate the amplitude of these changes.

EFFECT OF RAISING VAPOUR TENSION.

Jy. 12, beginning at 8 hr. Sunlight till 14 hr.; then "weeping" fog (a fine drizzle).

Min.:	60	60	60	25	35	humidity raised to	60	humidity lowered			
Rate:	11	7	13	29	-22	*ca.* saturation at 12.04	57	at 13.06			
Min.:	60	60	60	60	60						
Rate.:	50	43	50	42	35						

Jy. 15, beginning with 7 hr. reading. Sunlight till 10.54, then high fog 10.54-16.15

Min.	60	60	30	uviol glass mirrors at	30	20	29	humidity raised to *ca* saturation						
Rate:	42	28	20	8.30 hr.	0	-30	-21	at 9.49						
Min.:	11	humidity lowered		16	light reduced			38	high		6	25		
Rate.:	82	to normal at 10		0	by blue glass 10.16			16	fog		50	55		
Min.:	35	red glass in place of blue		30	10	20	screen removed at 13 hr.		60	60	60	sun at 16.15		
Rate.:	69	at 12		90	-30	45	diff. light		20	20	65	hr.		

Min.: 60 60 60
Rate.: 45 95 47

Jy. 16, beginning with 8 hr. reading. Sunlight (figure 10):

Min.: 60 48 12 25 10 16 leaves cut off 9 uviol mirrors low r.h. 10.03
Rate: 23 19 -50 -12 60 0 9.51 67
Min.: 20 40 4 r.h. raised to *ca.* sat. 40 red high 16 19 blue high 16 normal conditions
Rate.: 105 8 0 at 11.07 57 r.h. 130 63 r.h. 75 restored
Min.: 30 mirrors 13.05 45 chamber closed -uviol max. t. and illumination
Rate.: 42 40 at 13.50
Min.: 10 23 red 27 blue 10 12 normal conditions 48 60 60
Rate.: 18 83 100 120 100 restored 15.12 56 30 35

Jy. 25, beginning with 8 hr. reading. Thin high fog:

Min.: 60 60 60 60 60 78 humidity raised at 42 60 60 60 60 60 60
Rate: 20 - 5 2 6 0 10 13.18 43 45 30 30 25 37 20

Jy. 26, beginning with 8 hr. reading. Sunlight. Maximum t. 71:

Min.: 60 60 60 60 40 humidity raised at 11.40. Wilting 20 20 40 20 fog at 13.30 40 60
Rate: 10 5 0 −5 15 in other plants. 0 0 15 15 67 45
60 60 60 60 60
25 40 25 15 12

The raising of the vapour tension in this instance (July 26th) was not followed by a very marked effect. The absence of minus rates after 11.40 means, however, that this part *was not affected to the point of wilting*, which on the other hand was very evident in neighbouring plants. With the advent of fog the rate rose.

Ag. 12, beginning at 7 hr. Sun all day. Part inclosed all day in chamber with mirrors and uviol glass. Hour periods. Humidity raised to *ca* saturation 14 hr.

Rate: 20 25 30 35 25 35 20 35 45 55 75 25 15
Temp.: 62 117 122

The internode was shaded at 14.50 hour. The high temperatures affording a rigorous condition were probably responsible for the lesser total growth on August 12th, as compared with August 11th (see fig. 8). We note the exceptionally high rates from 8-12 hour which occurred very seldom.

EFFECT OF CHANGES IN ILLUMINATION

The preceding data show that conditions (shade, high relative humidity) which reduce evaporation from the plant, or which reduce its transpiring surface, permit increased growth. The use of shade however, reduced the light. It remained to determine what effect

changes in the amount of illumination would have. Temperature conditions were not controlled; nor was it necessary since the varying conditions afforded fluctuations in both directions, so that the data which follow offer fairly conclusive evidence that the maximum possible illumination to which the plant is normally exposed to in its environment is itself without direct effect in limiting or reducing growth. The records of the following days are now considered.

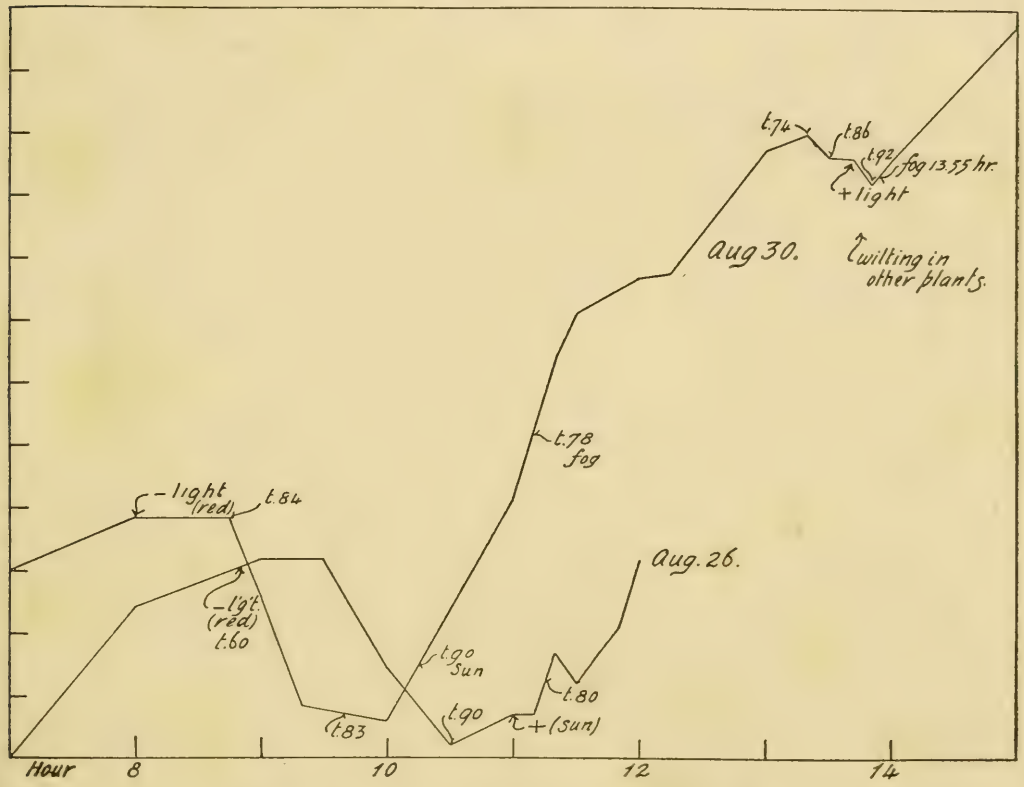

Figure 11. Curves of total growth for August 26 and 30.

Jy. 14, beginning with 8 hr. reading (fig. 10):

Min.:	60	60	60	60	sun at	60	25	uviol screen at 12.25		35	blue screen at 13		24	red screen at 13.30						
Rate:	37	35	20	15	11	20	0			33			40							
Min.:	10	26	high fog at 14		22	uviol 14.22		38	60	normal conditions restored at 16.05			60	50	10	60				
Rate.:	60	115			95			150	100				65	66	26	26				

Growth proceeded after previous cessation on placing the uviol glass screen, thus raising the temperature without altering the illumination. This might of course have occurred in any event.

Reduction of light was followed by increased rates but these were much inferior to those attained with full illumination after 15 hour when high fog prevailed. The amount of growth for 38 min. was at an hour rate of 2.1 mm., about equal to a recorded amount of growth for an entire hour on August 24th (datum: 2 mm. 14-15 hour).

July 15th, see page 31 (fig. 10).

The effect of the screen and mirrors was to impose insolation on the otherwise shaded sides of the internode and to raise the temperature. This was done at 8.30 hour when shrinkage was to be expected, but recovery proceeded normally at a very high rate (1.1 mm. per hour) on increasing the humidity at 9.49 hour. Reduced light at 10.16 hour permitted an increased rate after it had been lowered by reduced humidity. A high fog intervening favoured still higher rates. Change from blue to red was followed by a slight advance in rate for 30 min. when lower rates persisted till 15 hour when they jumped to 65. The greatest change in rate, therefore, occurred during high illumination but induced by raising the humidity. The greatest amount of growth for a sustained period occurred with maximum illumination (sun plus mirrors) during the late afternoon.

Aug. 26, beginning with 7 hr. reading (fig. 5):

Min.:	60	60	red	screen	60	30	30	30	30	red	screen	10	10	10	10	10	
			at 8.50							removed at							
Rate:	21	28			15	0	70	-50	20	11 hr.		0	120	-60	60	48	
Air t.:		60			60	83		90	90								
Min.:	10	60	60	60	60	60	60	60	60								
Rate.:	132	45	53	36	51	28	42	31	20								
Air t :			66														

The growth curve for this day was also decidedly irregular from 9.30 on and particularly so between 11 and 14 hour. The possibility of instrumental error was appreciated but the character of the night records, which were uniformly smooth, and those for the same internode on other days before and after the 26th, which bore the same character, exclude this possibility. It was, however, a long, slender internode in which irregular growth might well be expected. In spite of reducing the light but raising the temperature in the chamber in the morning, shrinkage occurred. Increase of light at 11 was followed in 10 min. by high rates for short periods with a brief period of shrinkage intervening.

Aug. 27, beginning with 8 hr. reading. Hour periods.

Rate:	25	20	10	0	blue screen at 11	-20	45	10	27	63	60	60	17

Reducing the light did not induce more rapid rates of growth nor were the rates at the time of normal most rapid growth as high as they sometimes were with full insolation, *e.g.*, on August 24th (table 3).

Aug. 29, beginning with 8 hr. rea ding; high fog all day. Hour periods. Uviol glass till 14 hr.

Rate:	20	0	19	7	-8	-5	glass removed	**42**	68	65	40	20		
Temp.:					78	85	at 14 hr.		73			57		

The temperature remained high in the chanber (78-85 degrees) till the removal of the glass, when it rapidly fell, with a raising of humidity.

Aug. 30, beginning with 7 hr. reading. Red screen on at 8 hr. till 13.42 hr. Wilting evident in controls at 14 hr. Sun till 10.45; dense high fog 11.25-13.25; sun till 13.55 then fog (fig. 11).

Min.:	60	60	red screen	45	15	20	40	60	fog	20	10	30	15	45	20	
Rate:	17	18	at 8	0	-100	-105	7	25		135	90	22	4	53	15	
Temp.:		59			84		90			78			76	74		
Min.:	10	12	red screen	8	10	wilting	60	60	60	60	60	60				
			removed			evident										
Rate.:	-42	-5	13.42	-60	48		43	48	43	37	25	15				
Temp.:	88	92			78		66		62	62						

Reduction of light did not prevent minus rates for two hours for which high temperatures inducing transpiration were responsible. High rates followed the removal of the red screen after a short interval of 8 min. which concluded a second period of shrinkage on this day. Conditions were complicated by the intervention of fog, which, the temperatures and humidity becoming more favourable, permitted more rapid growth for a period, though the turning point was passed while the sun was still shining and the temperatures high. It is difficult to see any dominating influence except that of temperature and humidity and their effect on transpiration.

Aug. 31, beginning with 6 hr. reading, the chamber being closed with uviol glass till 17.15:

Min.:	60	60	60	60	60	20	20	cool breeze at 10.45 temp. dropped				20	20	20	20	60
Rare:	14	7	4	-31	-7	-9	6	to 72 in 15"				69	36	30	12	19
Temp.:			63		69	100	95					72	104	106		110
	red glass on				30	30	60	60	60	uviol screen		60	60	60		
	at 13 hr. for									removed						
	30 minutes				20	20	10	15	75	17.15		50	27	18		
					100		109	90	70					54		

The reduced illumination at 13 hour was not followed by an increased growth rate, which became rapid only in the late afternoon. It seems clear that temperatures were controlling.

The foregoing experiments in which the changes in illumination were imposed on the growing part lead clearly to the conclusion that these alone are of very minor influence on the rate, or on the total amount of growth. We should probably, however, attribute a small temporary positive effect to light within the normal range of insolation

in view of the results obtained by Blaauw ('14) but that a reverse effect —that is an inhibitory one—exists cannot be inferred from the evidence. As we have seen, the maximum slowing up of growth occurs during the early morning hours of increasing illumination, but precisely the reverse occurs after the ten o'clock minimum has been attained, and this while the insolation is approaching its maximum values.

"That light can[1] be held to account for the retardation of growth during the morning hours as above indicated has been shown to be an untenable view, since it was found possible experimentally to alter the rates both positively and negatively quite independently of the constancy, increase or decrease of illumination, even when this has been increased with respect to the growing part by insolation from three directions. There seems indeed to be no maximum insolation normally occurring in the field which can cause any cessation or inhibition of growth when conditions which insure water supply to the growing part obtain."

This conclusion accords with not a few critical studies already recorded. One may cite the results of R. H. Lock ('04) and by A. M. Smith ('06) in whose essays earlier pertinent observations and views are quite fully reviewed. With particular reference to the relation of light and growth, A. M. Smith found "no decisive case of retarding light effect" even under the light conditions of Ceylon, nor did Lock, who worked there two years earlier, also on *Dendrocalamus*. Collins and Kempton ('14) recorded higher growth rates in *Zea* during daylight than during the night; and Copeland ('16) found for *Dioscorea* that the "rate of growth of vigorous young shoots is but slightly, if at all, influenced by the illumination" and that "the part of the stem which executes movements . . . ceases to elongate in the darkness". In *Lagerstroemia* he ('13) found however that the tendrils seem to offer a special case in which "the growth region is longer during the night" and that growth then occurs in considerable measure. On this point, however, specific data are not given, since the purpose of the paper was aside from this point.

On the other hand Lock concluded that there was a marked parallelism between humidity and growth[2] while temperature had the opposite effect. Although growth was usually greater at night, the opposite could occur in the daytime if temperature and humidity conditions were sufficiently favourable. Lock recorded shrinkage on one occasion in

[1] In my preliminary account ('16, p. 58) this verb was printed by error in the negative but obviously reversed my meaning. The present quotation is taken from the original MS. without alteration.

[2] One may here recall a paragraph from deVries ('74, p. 318) in which emphasis is placed on humidity.

the daytime. And A. M. Smith came to a similar view, viz., that in *Dendrocalamus* "two factors of the physical environment in turn limited the rate of growth of the culms (1) the temperature of the culm and (2) the supply of water to the culm. The second factor being intimately connected with the amount of water drawn off by the transpiration of the adult culms on the same rhizome, depends in its turn on two factors: (1) the humidity of the atmosphere, (2) the intensity of the light". Further, "the cases of the runner shoots of *Capparis* and *Stifftia* are explicable on the hypothesis that the supply of water is the limiting factor by day and the temperature by night. No decisive case of retarding light effect was obtained".

The influence of increasing humidity conditions in accelerating growth in the fleshy fruits of *Lycopersicum* has also been recognized by MacDougal ('19). The cessation of growth, or shrinkage, following on conditions leading to excessive transpirational loss, as occurs in the early portion of the forenoon in *Eriogonum*, adds another instance to an already long list of plants in which the same has been observed, *e.g.*, *Gossypium* (W. L. Balls, '12, Lloyd, '13), *Helianthus* (Balls, '12, MacDougal '18), to cite more recent results,[1] to which may be added the cases of net water loss in leaves measured by Livingston and Brown (12) and by myself ('12, '13, '20).

It is evidently felt and tacitly if not expressly admitted by some of the above quoted authorities that a small light effect may be present but, because of the masking effect of other factors, is not obvious enough for measurement under the conditions of field study. The accurate studies of Blaauw ('14) on *Phycomyces* and *Helianthus* would seem to justify this, for he found a temporary depressing effect of light when first admitted on *Phycomyces*, followed by a temporary excitation; and the reverse on *Helianthus*. Blaauw, however, specifically contests and controverts the classical error of the supposed inhibition of growth by light as formulated by Pfeffer from the work of Vines and others then available, and it is largely to the same end that the study here recorded was undertaken.

Release from this mistaken conception, recognized as such by MacDougal ('03, '15) in 1903, has gone hand in hand with those studies on growth which latterly directed attention to the role of colloids (emulsoids). Of comparative interest in the present connection are the results attained by MacDougal, MacDougal and Spoehr, E. B. Shreve, Borowikow, Lloyd and others[2]. In particular the behaviour of *Opuntia*

[1] For others see papers of Lock and of Smith.

[2] Additional pertinent literature will be found cited in those papers of these authors, mentioned in the list accompany the present paper.

(MacDougal, '16; MacDougal and Spoehr, '17) should be mentioned here. In this form, the total behaviour in respect of growth is precisely the reverse of that in *Eriogonum*. These two types indeed exemplify two physiologically widely different kinds of plants, which however are not coextensive with succulency and non-succulency. *Opuntia* contains pentosan emulsoids in large amounts (Spoehr, '19, Lloyd, '19, Stewart, '19) in high concentration, and may therefor be assumed to be capable of displaying imbibition pressures sufficient to account for measurable changes of volume of the plant body, according to the varying conditions of acidity.

The march of growth is such that acceleration takes place during the hours from sunrise till noon, "parallel to the disintegration of the clogging acids and the rising capacity for imbibition" (MacDougal and Spoehr, '17, p. 310). The cessation of growth after the noon hour calls for other as yet undetermined factors, since the "water holding capacity of the tissues is highest when the acidity is lowest" (E. B. Shreve, '16) and this occurs in the late afternoon (Richards, '15; Long, '15): and since transpiration is low throughout the day (Livingston, '06) and the stomata are closed (Shreve, 1, *c.*)

From the present account we have seen that *Eriogonum* presents a far different picture. In this the cells of the growing region are delicate protoplasmic utricles, with thin cell-walls, and the emulsoids of the vacuolar sap are present only in very low concentration, and would therefore be capable of exerting but limited pressures as compared with the osmotic pressures due to the presence of salts, sugars, etc. A tissue composed of such cells is chiefly an osmotic mechanism, and osmotic pressures must be regarded as of first importance in premitting and maintaining growth rates. It is the same sort of mechanism as occurs in the roots of *Helianthus*, in the submersed roots of which Borowikow ('13) however, found growth to be influenced by the alterations in the hydratation capacity of the emulsoids. The same might be postulated of *Eriogonum*, but for the apparent absence of evidence of suitable acid concentrations, and of the necessary changes in them. Professor H. M. Richards found the acid content of *Eriogonum* collected from plants, growing in 1918 in the same spot as those on which my studies were made, to be, per gram of fresh material in terms of N/20 alkali, 4.75 c.c. at 9 hour, 4.90 c.c. at 15 hour and 4.70 c.c. at 18 hour.

Until we know more about the physiology of this plant, it is unprofitable to speculate on the possibilities from this point of view. We know, however (Lloyd, '17, '18) that protoplasm as an emulsoid complex is extremely sensitive to minor changes in acid and alkali concentration, and while some protoplasm will cease to function in the presence of

concentrations as high as those which prevail in the tissues of cacti and of *Eriogonum*, it is evident that, under such conditions of tonus, even the changes in acid concentration indicated by the figures given just above may have some slight significance, at least in altering the permeability of the protoplasmic membranes, or the physical properties of the cell wall.

The absence of this sort of evidence makes the question as to the net growth accretion of the early afternoon in *Eriogonum* difficult of elucidation. The loss of water and the concomitant shrinkages, and the recovery until the original early morning volume is attained, seem to point to the relatively simple relation of income and outgo of water. Beyond this point, however, it seems necessary to assume that other sources of energy are being drawn upon. Increasing soil temperatures in the afternoon is probably a contributory factor in water absorption. We may suppose that the products of photosynthesis accumulated during the morning become available for maintaining the turgidity of the expanding cells, and for the complex operations which include enzymatic and other activities conditioning growth in the complete sense. These factors obviously include the rôle of substances affecting the dispersion of cell-wall and protoplasmic colloids, affecting the extensibility of the former and the permeability of the latter.

SUMMARY.

1. The march of growth in Eriogonum, in the particular situation in which the foregoing study was carried on, is the following: The night rates are low and nearly constant, the low night temperatures being the limiting factor. Humidity at night is always high. There is generally a slight acceleration of growth after dawn till 7 hour, though the rate may and frequently does remain constant. From 7 till 10 hour growth slackens, and frequently shrinkage occurs. This is to be referred to excessive transpirational activity, which is checked on wilting by stomatal closure. Recovery of the original volume then sets in, and by noon is usually complete. The earlier portion of the afternoon is a period of net increase in volume, when a net advance in growth is made. The maximum rate may be reached by the 15 hour or as late as the 18 hour, more frequently at 16 or 17 hour. Afterwards the rate of growth falls during two or three hours till the night rate is assumed.

2. It was evident that the most rapid growth rates might be attained during hours of maximum illumination; and experimentally it has been shown that even abnormally high rates might obtain under the most severe conditions of illumination possible by the use of full insolation

increased by reflectors. No evidence that a retarding effect of light on growth was obtained.

3. Other experiments show that humidity is a controlling factor of the highest importance. Within the limits available under the experimental conditions, the temperatures were not limiting if humidity was sufficiently high.

4. Growth rates could also be increased by the removal of leaves or reduced by the removal of conducting tissues.

5. Although other factors than changing water content, leading to net increase in the solids of the growing tissues (increase in cell walls chiefly) are especially effective in the afternoon, the vacuolar water remains the bulk-maintaining and expanding material, since changes in the environment which affects the water loss from the surface of, or its supply to, the growing part also affect the growth rates during the afternoon as well as during the morning.

6. The minute amounts of vacuolar emulsoids, namely those aside from the protoplasm and cell-walls, preclude attributing to them any gross contributory effect in growth or shrinkage. Alterations in the protoplasm as an emulsoid complex affecting its permeability, and therefore its behaviour as an osmotic mechanism; or in the collophysical properties of the cell-walls and their relation to extension under osmotic pressure, with concomitant permanent accretions, are probably to be recognized as factors to be reckoned with in growth. With regard to the relative importance of imbibition by emulsoids as a growth mechanism as compared with osmotic pressure, *Opuntia* and *Eriogonum* bear a similar relation to each other as certain pollen grains (*e.g.*, *Phaseolus*) on the one hand and the embryo-sac (Lloyd, '16*b*) on the other.

The effect of such conditions, if they obtain in *Eriogonum*, are masked by the greater effects of the osmotic mechanism as such.

McGill University.

PROTOCOL TO ACCOMPANY FIGURE 7.

s, sun; *hf*, high fog; max. temperature Fahr. in italics; *df*, dense high fog; *rl*, red light screen; *bl*, blue light screen; *uv*, uviol glass screen.

July 21, *s*; 22, *s*; 23, *hf*; 24, *s 71*; 25, *hf*; *s* after 14 hr. *71*; 26, *s*, *hf* after 14 hr. *71*; 27, *s 75*; 28, *s*; 29, *s*, *hf* after 13 hr.; 30, *hf*; 31, *s*.

August 2, *s*; 3, *df 63*; 4, *df 55*; 5, *df*, *s* after 13 hr. *66*; 22, *hf* 9 hr. *59*; 12 hr. *75*; 13 hr. *80*; 18 hr. *59*; 23, *s*, *hf* for 15 min. at 10.46 hr.; 9 hr. *75*; 12 hr. *77*; 13 hr. *67*; 18 hr. *59*; 24, *s*, *hf* after 14 hr.; *uv* 11.35, *104*; 25, *hf*; 8.30 hr. *59*; 12.30 hr. *71*; 15 hr. *66*; 18 hr. *56*; 26, *s 90*; *rl* 9-11 hrs.; 27, *hf*; *bl* 11 hr. on *88*; 28, *df*; 29, *df*; *uv* 8-14 hrs. *85*; 30, *s*; *hf* 10.45; *s* 13.25; *hf* 13.55; *rl* till 14 hr. *90*; 31, *s*; *uv*.

S. 1, *s*; *uv*; *119*; 2, *s*; *uv hf* 16 hr.; *107*; 3, *s*; *98*; 4, *s*; 8.40 hr. *87*; 13 hr. *105*; 16 hr. *86*; 17 hr. *77*; 20 hr. *55*; 5, *s*; *hf* 15 hr.; 6, *hf*; *s* 14.30 hr.; *hf* 16 hr; 7, *hf*; *s* 14 hr.; 8, *s*; 9 hr. *95*; *uv*; 10 hr. *104:* 18 hr. *63*; 9, *s*; *Uv*; 9 hr. *89*; 10 hr. *100*; 11 hr. *103*; 12 hr. *110*; 13 hr. *85*; 15, hr. 80; 20 hr. *59*; 10, *s*; *hf* 14 hr.; 11, *hf*; *s* 10 hr.; *hf* 10.30 hr.; 12, *hf*.

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DIRECT DERIVATION OF THE COMPLEMENTARY THEOREM.*

By J. C. FIELDS, PH.D., F.R.S.

The statement of the Complementary Theorem involves only differences between complementary orders of coincidence and the difference between the number of the conditions imposed on a sufficiently general rational function by a given basis and the number of the conditions imposed on the same function by the complementary basis. It would appear therefore that it should not be a necessary preliminary to the proof of the theorem to determine a formula for the actual number of the conditions imposed on a rational function of given form by a given set of orders of coincidence corresponding to a specific value of the variable z. The proof developed in what follows does as a matter of fact dispense with the aid of formulae of the type just referred to.

Let

1. $$f(z,u) = u^n + f_{n-1}u^{n-1} + \ldots\ldots + f_o = 0$$

be an algebraic equation in which $f_{n-1}, \ldots\ldots, f_o$ are rational functions of z. A rational function of (z, u) can be written in the form

2. $$H(z,u) = \frac{N(z,u)}{Q(z)} + P(z,u)$$

where $N(z,u)$ and $P(z,u)$ are polynomials in (z, u) of degree $n-1$ in u, the degree in z of $N(z,u)$ being less than the degree of $Q(z)$. We shall suppose (τ) to be a basis of coincidences relative to the equation (1), the partial bases corresponding to the finite values of z and to the value $z=\infty$ being indicated by $(\tau)'$ and $(\tau)^{(\infty)}$ respectively. The number of cycles corresponding to a value $z=a_k$ we indicate by r_k. The elements of the basis (τ) are connected with the elements of the complementary basis $(\bar{\tau})$ by the relations

3. $$\tau_s^{(k)} + \bar{\tau}_s^{(k)} = \mu_s^{(k)} - 1 + 1/\nu_s^{(k)};\ s = 1, \ldots, r_k,$$
$$\tau_s^{(\infty)} + \bar{\tau}_s^{(\infty)} = \mu_s^{(\infty)} + 1 + 1/\nu_s^{(\infty)};\ s = 1, \ldots, r_\infty,$$

where the orders of the cycles are represented by the symbols $\nu_s^{(k)}$ and where the symbols $\mu_s^{(k)}$ designate the orders of coincidence of the function $f_u'(z,u)$.

*This paper was read at the Harvard Meeting of the American Mathematical Society in September, 1916. The writer has however neglected to publish it in the interval.

We shall designate by $H'(z,u)$ and $H^{(\infty)}(1/z,u)$ the general rationa functions of (z,u) conditioned by the partial bases $(\tau)'$ and $(\tau)^{(\infty)}$ respectively. The writer has shewn* that the necessary and sufficient conditions in order that a rational function $\bar{H}(z,u)$ may have the orders of coincidence $\bar{\tau}_1^{(k)},\ldots,\bar{\tau}_{r_k}^{(k)}$ for the value $z=a_k$ are obtained on equating to 0 the principal residue relative to $z=a_k$ in the product

4. $$\bar{H}(z,u)\,H_k(z,u)$$

where we employ the notation $H_k(z,u)$ to designate the general rational function conditioned by the orders of coincidence $\tau_1^{(k)},\ldots,\tau_{r_k}^{(k)}$ for the specific value $z=a_k$. It is also readily shewn that we impose on $\bar{H}(z,u)$ the orders of coincidence $\bar{\tau}_1,\ldots,\bar{\tau}_{r_k}$ relative to the specific value $z=a_k$ when we equate to 0 the principal residue relative to the value $z=a_k$ in the product (4), after we have imposed on the factor $H_k(z,u)$ any assigned set of conditions relative to finite values of the variable z other than the specific value here in question. In particular we see that we impose the orders of coincidence $\bar{\tau}_1^{(k)},\ldots,\bar{\tau}_{r_k}^{(k)}$ on the function $\bar{H}(z,u)$ when we equate to 0 the principal residue relative to $z=a_k$ in the product

5. $$\bar{H}(z,u)\,H_k'(z,u)$$

where $H_k'(z,u)$ designates the most general function included under $H'(z,u)$ such that the principal residues in the product relative to all finite values of the variable z other than $z=a_k$ vanish identically. Here $\bar{H}(z,u)$ is supposed to be a form as general as we will but chosen in advance. Thereafter $H_k'(z,u)$ is chosen accordingly and is included under $H'(z,u)$. In the product (5) then there can only be question of principal residues relative to the specific value $z=a_k$ and to the value $z=\infty$. If one of these residues is 0 then the other must be 0 also. On equating to 0 the principal residue relative to the value $z=\infty$ in the product (5) therefore we at the same time equate to 0 the principal residue relative to the value $z=a_k$ and therewith impose on $\bar{H}(z,u)$ the orders of coincidence $\bar{\tau}_1,\ldots,\bar{\tau}_{r_k}$ for this value of the variable. Consequently on equating to 0 the principal residue relative to the value $z=\infty$ in the product

6. $$\bar{H}(z,u)\,H'(z,u)$$

we impose on $\bar{H}(z,u)$ the orders of coincidence $\bar{\tau}_1,\ldots,\bar{\tau}_{r_k}$ relative to the value $z=a_k$. The principal residue relative to $z=a_k$ in the product (6) will then be 0. This holds for every finite value $z=a_k$. On

*On the Foundations of the Theory of Algebraic Functions of one Variable. *Trans. Roy. Soc.*, London, Series A, Vol. 212, p. 347.

equating to 0 the principal residue relative to the value $z=\infty$ in the product (6) therefore we impose on $\bar{H}(z, u)$ the orders of coincidence furnished by the partial basis $(\bar{\tau})'$ and equate to 0 the principal residues in the product relative to finite values of z. The vanishing of the principal residue relative to the value $z=\infty$ in the product (6) then furnishes the necessary and sufficient conditions in order that the function $\bar{H}(z, u)$ may have the orders of coincidence required by the partial basis $(\bar{\tau})'$.

The necessary and sufficient conditions in order that a rational function $\bar{H}(z, u)$ may have the orders of coincidence $\bar{\tau}_1^{(\infty)}, \ldots, \bar{\tau}_{r_\infty}^{(\infty)}$ for the value $z=\infty$ are obtained on equating to 0 the principal residue relative to the value $z=\infty$ in the product

$$7. \qquad \bar{H}(z, u)H^{(\infty)}(1/z, u).$$

The necessary and sufficient conditions in order that a rational function $\bar{H}(z, u)$ may be built on the basis $(\bar{\tau})$ are obtained on equating to 0 the principal residues relative to $z=\infty$ in the two products (6) and (7). The question arises as to how far the two sets of conditions on the coefficients of $\bar{H}(z, u)$ so obtained overlap? To determine this we write $\bar{H}(z, u)$ in the form

$$8. \qquad \bar{H}(z, u)=z^{-i-1}((1/z, u)) + \sum_{t=0}^{n-1} \sum_{r=-i}^{j} a_{r,t} z^r u^t + \prod_k (z-a_k)^{i_k} \bar{P}_1(z,u)$$

where $\bar{P}_1(z, u)$ is a polynomial in (z, u) and where $j+1=\sum_k i_k$. The exponents i_k we assume to be chosen sufficiently great to ensure that the product $\prod_k (z-a_k)^{i_k} \bar{P}_1(z, u)$ satisfies the conditions imposed by the partial basis $(\bar{\tau})'$ and i we take sufficiently great to ensure that the orders of coincidence of the expression $z^{-i-1}((1/z, u))$ for the value $z=\infty$ do not fall short of those furnished by the partial basis $(\bar{\tau})^{(\infty)}$.

Now on substituting in the products (6) and (7) the expression for $\bar{H}(z, u)$ given in (8) we see that the principal residue relative to $z=\infty$ in the former product does not involve coefficients in the expression $\prod_k (z-a_k)^{i_k} \bar{P}_1(z, u)$ and that the principal residue relative to $z=\infty$ in the latter product does not involve coefficients in the expression $z^{-i-1}((1/z, u))$. The conditions common to the two sets of conditions obtained on equating to 0 the principal residues relative to $z=\infty$ in the products (6) and (7) then evidently involve only the coefficients $a_{r,t}$ in the expression for $\bar{H}(z, u)$ given in (8). Supposing l to be the number of these common conditions and writing $H'(z, u)$ in the form for a rational function given in (2) we see on equating to 0 the principal residue relative to $z=\infty$ in the product (6) that those conditions which

involve the constants $a_{r,t}$ only will not be affected by the higher powers of z which present themselves in the polynomial $P(z, u)$. These conditions among others will then be obtained on equating to 0 the principal residue relative to $z = \infty$ in the product

9. $$\bar{H}(z, u)H''(z, u)$$

where $H''(z, u)$ is included under the general function $H'(z, u)$ and has the form

10. $$H''(z, u) = \frac{N(z, u)}{Q(z)} + P_1(z, u)$$

the function $P_1(z, u)$ being a polynomial to which we may assign a limited degree in z. Under the function $H''(z, u)$ will then be included l linearly independent functions $H_1'(z, u), \ldots, H_l'(z, u)$ such that the l common conditions referred to above will be obtained on equating to 0 the principal residues relative to $z = \infty$ in the l products

11. $$\bar{H}(z, u)H_\sigma'(z, u), \quad \sigma = 1, \ldots, l,$$

however general $\bar{H}(z, u)$ may be to start with.

Again however general $\bar{H}(z, u)$ may be there will evidently be included under the general function $H^{(\infty)}(1/z, u)$ functions $H_\sigma^{(\infty)}(1/z, u)$, in number l, such that the principal residues relative to the value $z = \infty$ in the l products

12. $$\bar{H}(z, u)\ H_\sigma^{(\infty)}(1/z, u), \quad \sigma = 1, \ldots, l,$$

have precisely the same linear forms in the constants $a_{r,t}$ as the principal residues relative to the value $z = \infty$ in the corresponding products (11). In the products

13. $$\bar{H}(z, u)\{H_\sigma'(z, u) - H_\sigma^{(\infty)}(1/z, u)\}, \ \sigma = 1, \ldots, l,$$

then the principal residues relative to the value $z = \infty$ are identically 0 however general $\bar{H}(z\,u)$ may be. This however can only be when we have identically

14. $$H_\sigma'(z, u) = H_\sigma^{(\infty)}(1/z, u), \quad \sigma = 1, \ldots, l.$$

The l functions $H_\sigma'(z, u)$ are therefore conditioned not only by the partial basis $(\tau)'$ but also by the partial basis $(\tau)^{(\infty)}$. The l functions in question then are built on the basis (τ). On equating to 0 the principal residues relative to the value $z = \infty$ in the products (6) and (7) therefore the common conditions on the coefficients of $\bar{H}(z, u)$ arise from equating to 0 the principal residues in products of the type

15. $$\bar{H}(z, u)H_\sigma'(z, u)$$

where $H_\sigma'(z,u)$ is a rational function built on the basis (τ). Also each such independent product will furnish an independent condition since in

any such product the principal residue relative to $z = \infty$ is not identically 0 when $\bar{H}(z, u)$ is taken sufficiently general. On designating by N_τ and $N_{\bar{\tau}}$ respectively the numbers of the arbitrary constants involved in the general rational functions built on the bases (τ) and $(\bar{\tau})$ we have $l = N_\tau$ and the number of the conditions common to those imposed on the function $\bar{H}(z, u)$ by the partial bases $(\bar{\tau})'$ and $(\bar{\tau})^{(\infty)}$ respectively is precisely N_τ.

Suppose (t) to be a basis on a lower level than either of the bases (τ) or $(\bar{\tau})$. We start out with a sufficiently general rational function $\bar{H}(z, u)$. In particular we assume this function to include the general rational function built on the basis (t). The numbers of the conditions imposed on the function $\bar{H}(z, u)$ by the partial bases $(t)'$ and $(t)^{(\infty)}$ respectively we shall indicate by M_t' and $M_t^{(\infty)}$. The numbers of the conditions imposed on $\bar{H}(z, u)$ by the partial bases $(\bar{\tau})'$ and $(\bar{\tau})^{(\infty)}$ will then be $M_t' + \sum_k' \sum_{s=1}^{r_k} (\bar{\tau}_s^{(k)} - t_s^{(k)}) \nu_s^{(k)}$ and $M_t^{(\infty)} + \sum_{s=1}^{r_\infty} (\bar{\tau}_s^{(\infty)} - t_s^{(\infty)}) \nu_s^{(\infty)}$ respectively. From what precedes then the number of the independent conditions imposed on $\bar{H}(z, u)$ by these partial bases simultaneously, that is by the basis $(\bar{\tau})$, will be

$$16. \qquad M_{\bar{\tau}} = M_t' + M_t^{(\infty)} + \sum_k \sum_{s=1}^{r_k} (\bar{\tau}_s^{(k)} - t_s^{(k)}) \nu_s^{(k)} - N_\tau .$$

Similarly the number of the independent conditions imposed on $\bar{H}(z, u)$ by the basis (τ) will be

$$17. \qquad M_\tau = M_t' + M_t^{(\infty)} + \sum_k \sum_{s=1}^{r_k} (\tau_s^{(k)} - t_s^{(k)}) \nu_s^{(k)} - N_{\bar{\tau}}.$$

Evidently $M_\tau + N_\tau = M_{\bar{\tau}} + N_{\bar{\tau}}$ since these expressions both represent the number of the arbitrary constants involved in the original function $\bar{H}(z, u)$. We therefore have $M_\tau - M_{\bar{\tau}} = N_{\bar{\tau}} - N_\tau$ and by combining (16) and (17) we obtain the complementary theorem in the form

$$18. \qquad M_\tau - \tfrac{1}{2} \sum_k \sum_{s=1}^{r_k} \tau_s^{(k)} \nu_s^{(k)} = M_{\bar{\tau}} - \tfrac{1}{2} \sum_k \sum_{s=1}^{r_k} \bar{\tau}_s^{(k)} \nu_s^{(k)}.$$

TRANSACTIONS

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RESEARCH

By

His Excellency The Duke of Devonshire, K.G., Governor General of Canada, Honorary President of the Royal Canadian Institute.

His Excellency, addressing the members of the Royal Canadian Institute, spoke as follows:

Mr. President, Ladies and Gentlemen:

It was perhaps rather too light-heartedly that I accepted the invitation conveyed to me some months ago by my good friend, Dr. Alexander Fraser, that I should deliver the Inaugural Address this year to the Royal Canadian Institute and that my subject should be "Research." I confess that in the intervening months I have had some extremely anxious and critical moments. (Laughter.) I was well aware of the responsibility of the undertaking and my fears were more than confirmed when I began to consider the lines upon which I should proceed this evening. There is, however, one advantage to myself personally and that is, if I had not accepted the invitation, I should, in all probability, have never acquainted myself, as I have now had the opportunity of doing, with the extremely valuable contributions to science which have been made by the Institute during its long and distinguished career. I could not help thinking that in tendering the invitation to me to speak to-night some of you may have had a sort of idea that I, like my famous and distinguished predecessor, may have been bottling something up, (laughter) and that from somewhere in the deep recesses of my mind I might have been able to produce some of the results which were produced out of his inverted crucible by my own ancestor, the Honourable Henry Cavendish, who, as many of you know, added much to the scientific knowledge of the world, as has been testified by those who have read his papers.

Many of you, no doubt, know something of that strange and ascetic individual. I do not now propose to treat of him and his peculiarities at any length. You are probably familiar with the story that although he started in life with emoluments, small even in those days, he found himself later in possession of a large fortune, certainly through no aid or work of his own as far as money-making was concerned. His bankers came to him—people generally have to go to bankers, for the bankers do not come to them—and informed him that he had a very substantial balance in the bank and suggested that some useful investments should

be made; but Henry Cavendish, speaking from behind a hydrogen jar, merely said: "Why do you bother me with this?"

Another story is that when a very distinguished colleague was visiting him his housekeeper reminded him that he should entertain his guest at dinner. His own habitual meal was a piece of mutton and a roll, and he replied: "Why, order two pieces." (Laughter.)

I assure you that if I had the knowledge and capacity to have thought out any portion of those problems to which he made such invaluable contributions, I should not have kept them entirely to myself. But I can further assure you that although I am not myself capable of making any useful or practical contribution to research those who have devoted their time to this great work may be sure of any assistance which I can possibly render. (Applause.)

The TRANSACTIONS OF THE ROYAL CANADIAN INSTITUTE contain many important contributions to research. They constitute a store of valuable information relating to a great variety of subjects. Where there are so many notable contributions it might be invidious to mention names, but certainly the Inaugural Addresses of the President and his predecessors in office are a striking and eloquent testimony to the importance which the Institute attaches to the inexhaustible field of research. To those who may not be well informed as to recent developments I can suggest no better course of study than that they should make a close perusal of these addresses. They illustrate different points of view but are all interesting, practical and suggestive.

For my purpose this evening I hope that you will understand that while I must inevitably appear to lay greater stress on the practical and commercial aspect of the problem, I wish to emphasize as strongly as possible the importance and value of research for its own sake and to make use of the word in its most extended application.

I know that I have achieved a certain amount of reputation throughout Canada as being an optimist, but I hope that it is not altogether that of a blind optimist. Without being too optimistic, I hope there is at any rate some justification for taking a more sanguine view than would have been possible a few years ago. You may feel that progress is slow, yet I cannot help feeling that a certain amount of substantial progress has been made. Various causes have, no doubt, contributed to such progress; but we must always bear in mind that events move slowly and that so far only beginnings have been made.

It may not be out of place to remind you as an instance of slowness of progress, perhaps also as an instance of sureness of progress, that it was as long ago as the year 1870 that a Royal Commission was appointed in England, over which it so happened that my grandfather, the seventh

Duke of Devonshire, to whom the President has already alluded, was appointed to preside. That Commission recommended that a Council and Minister of Science should be appointed in Great Britain. Well, it was not until after the beginning of the Great War that that recommendation was acted upon and such a Council was appointed. I am glad to say, too, that similar action was taken in Canada. Possibly the most important event in the record of progress was the debate which took place in the House of Commons at its last session. I confess that I am an old Parliamentary hand and know something of Parliamentary procedure and Parliamentary methods. I know that very often there is a long gap between the passing of pious resolutions and positive action. (Laughter). Neverhteless I venture to hope that the debate which took place in the Federal Parliament on May 7th of the present year did constitute a very genuine step in advance. That debate, I believe, not only expressed the views of the present House of Commons but I am confident that the measure under discussion, if placed before the country as a whole, would receive a very great degree of general support.

The problems which confront all governments to-day, and especially those ministers who are more closely connected with the administration of finance, are, as we all know too well, of a critical and rather serious nature. I am confident, however, that the objects which those, who lead the research movement, have in view are so generous and of such general utility that the taxpayer would willingly consent to the expenditure of public money on them. Public opinion has, perhaps, never been so strong as it is to-day, and when it concentrates on the question of research you will find that the demand will be so widely spread and so urgent that Parliament and ministers will endeavour, so far as lies in their power, to provide all the facilities needed for research. I should not like, on an occasion of this sort, to weary you with lengthy personal experiences or such ideas as I have formed for myself, but having been here for the last four years—and I may simply say that this is my birthday—(Applause) I had not finished my sentence—as Governor General. (Laughter.) This is a very auspicious day, for very many reasons, and very important ones. It was on November 11th, 1916, that I was sworn in and assumed the office of Governor General of Canada. The day will certainly be one of many, many happy and pleasant memories to myself. (Applause.) I would be most reluctant to assume to force down your throats anything like personal reminiscences or experiences. The habit of writing books of reminiscences has perhaps become too common (Laughter) and I am not going to be one of the guilty. But looking over the last four years I have had many very many exceptional opportunities, not only of seeing the great areas

and great tracts of this country, but I have had also a privilege that I value even more highly, that of making the acquaintance of many of Canada's citizens and of being able to ascertain their angle and their point of view.

While my mind has been greatly impressed by the growth and development of the country's industries and resources in agriculture, mining, forests, water power, etc., one is still more impressed by the opportunities that exist. You have only to travel the country to know these opportunities and when one sees the strides which have been made in so short a time he cannot but wonder what the possibilities are for the future.

In my office at Ottawa hangs the 35 mile to the inch Railway Map of Canada, issued by the Department of the Interior, with which you are probably all familiar. It bears the date 1920 and is, therefore, presumably more or less up to date. (Laughter.) But it so happened only a very few days ago that the Prime Minister came to see me. He found me, as I am very often to be found, standing upon a chair looking at that map. It was a model of perfection but he said it was already completely out of date. He added: "We have sent men right up to some place in the north, and you want a map double that size to get up to where that outpost has gone for the purpose of investigation and discovery." (Laughter.)

Another thought always strikes me when I regard that map. We hear a great deal about railways in this country, yet if you take that map—for it is a railway map after all—and if you look carefully at the area covered by railway lines, you cannot but be struck by the relatively extremely small portion which is served by any railway at all. Yet we have every reason to believe that those vast regions stretching away, even beyond the Arctic Circle, possess potentialities of the highest value. We confidently talk about the development of our resources and yet I am bound to say that we fall off somewhat when we attempt to define how they should be developed on business and scientific lines.

I know you will pardon me if I venture to allude to another feature which has struck me during my tenure of office, a far from pleasant one I admit. This is the appalling wastage which one sees going on all around in Canada to-day, whether in agriculture, in farm culture, in forestry, in fishing or in mining we are losing what ought to be extremely valuable products. I shall mention one instance only.

There is, perhaps, nothing which strikes any one coming from the Old Country and going through the Prairie Provinces more than to see the straw being absolutely and deliberately burned. I know that within the last two or three years efforts have been made to prevent this and

that in fact burning has been prohibited. Nevertheless it has seemed a strange paradox that while some of the best brains have been evolving, and are still evolving, types of wheat, oats and other agricultural products, best suited to climatic and soil conditions, it has been a more or less general practice in many parts of the country, not only to make no use of what ought to be a valuable annual product, but to deliberately destroy it. I know that not only agriculturists, but also eminent scientists, are to-day dealing with the problem of the utilization of this product, and I only mention it as an instance.

Again and again also I have heard the statement that land in many portions of Canada is not farmed but mined. The very benefits which a kind and generous soil confer on us are taken without anything being restored to it to help it continue its beneficent work. One hears on every side that this matter is engaging the attention of those who are best qualified to deal with it and I cannot help hoping that with the advance of knowledge and of science better and more economical methods will be found to prevail. (Applause.)

It is very tempting to one situated as I am to-night, to dilate upon the vast possibilities which we in Canada possess. Our known resources are enormous and as we gain knowledge of the less known regions the possibilities for the future become much vaster. May I take you back to the Finance Minister and remind you of the necessity and urgency of research from his point of view—and, after all, his point of view is the point of view of the taxpayers as a whole.

The developed wealth of Canada has been estimated at various amounts between eighteen billion and twenty-five billion dollars. The estimated developed wealth of the United States is put at three hundred billion dollars. Of course in the United States there are still great natural resources which are undeveloped but so also are there great natural resources in Canada, and the latter are, as yet, almost wholly untouched. If scientific research could be applied to the development of these resources I think it is safe to estimate that in ten years there would be not twenty-five billion dollars of developed wealth but something nearer one hundred billion dollars. Under these circumstances the present debt of Canada, which is about two billion dollars, would be an exceedingly light burden for the Dominion and the most cautious of Finance Ministers would be at his ease. (Applause.)

Ladies and gentlemen, I know that to an audience of this character it is not necessary for me to labour these points. On the one hand we know we have these great resources which are waiting to be transformed to the use and benefit of man. On the other hand it is for us to find the means whereby the transformation can be effected. (Applause.)

Touching the matter of research there are two other subjects to which I should like briefly to refer. Public Health and all that is involved in these words is occupying more and more of our attention. Enormous advances have been made, and are being made from day to day, in medical and surgical science, but if I may venture to use a painfully hackneyed and well-known expression, nearly two thousand years have elapsed since Juvenal wrote "Orandum est, ut sit mens sana in corpore sano" and the prayer is as urgent to-day as it was then.

The war, undoubtedly, disclosed conditions the gravity of which cannot be overlooked. I am not now referring to the loss or impairment of life as direct consequences of the war. I am not alluding to those who were killed in action, or wounded or maimed as a direct result of war, but to the physical and mental conditions which were found to exist in different countries when they were called upon to make preparation for war. Nor is there reason so far as I have been able to inform myself, to make an exception of any of the belligerent nations. In preparing and equipping ourselves for war we—and I say "we" in the broadest possible sense—undoubtedly found conditions prevailing which, to say the very least, give rise to great anxiety and call for inquiry. Many of you, I know, are familiar with the phrase of the Prime Minister of Great Britain, Mr. Lloyd George, "You cannot get A-1 workers out of a C-3 population." Mr. Lloyd George is a past master at the art of phrase-making, but he never coined a better or more pointed phrase. It summarizes the situation with which we are confronted.

I know that much has been achieved. There are great institutions throughout the world which have already done, and which from day to day are doing, notable work in advancing the science of Public Health. We owe a debt which we can never repay to the men and women who, by patient investigation and industry, have done so much to relieve human suffering and to the splendid munificence of those individuals who have made it possible for the skilled and trained researchers to do this beneficent work. In this connection I hope I may be allowed to take the opportunity of referring to the generosity of that distinguished citizen of Toronto and member of this Institute, Colonel Gooderham, in providing the Connaught Laboratories which did such great work during the war. (Applause.) That work, I feel confident, is only an earnest of what is to be done, not only in the distant, but in the very near future as well.

Though much has been accomplished in the way of medical research we all know that the field is a vast one and that the opportunities for further development are unlimited. However wonderful the results attained, the call is ever for more. No encouragement to research along

these lines should be omitted. No inducement to the research worker should be lacking and every possible assistance should be rendered to him in this great and noble work.

The only other subject on which I shall touch to-night is that of Historical Research.

After all, what is History? I speak subject to correction, but I believe I am right in saying that the word is derived from the Greek "ἱστορία" which was used by the Ionians in the 6th century B.C. to designate the search for knowledge in its widest sense. It meant inquiry, investigation, not narrative, and it was not till two centuries later that the historian—the reciter of stories—superseded the historian, the searcher after knowledge.

Even if we use the word in the more restrictive sense we have a vast field for the research worker. Human interest and activity is constantly broadening with the ever-increasing complexity of modern society and the more or less rapid emergence of social and economic conditions. We look to historic research to enlighten us as to how the corresponding needs were met in earlier times and how they developed into their present relative importance.

By a thorough study of the capacities and limitations of human nature we must search for the most progressive and practical means for the betterment of individual life and the improvement of social conditions, and it is to history—the record of human experience—that we must turn for guidance in that study.

I am afraid, ladies and gentlemen, that I have done no more than touch the fringe of this great subject of research. Many of you who are here this evening, I know, are giving their best attention to the problems which present themselves in this connection. Chief among these problems, in my opinion, and in the opinion of many others, is that of the supply of research workers. How and where are we to get the men and women qualified to carry on this work of research? This is a problem which not only we in Canada but the people in the Old Country and in the United States are seeking a solution for.

Here I should like to quote a memorandum of Dr. Macallum, Chairman of the Honorary Advisory Council for Scientific and Industrial Research. The memorandum in question referring to the problem just mentioned reads as follows:

"The Research Council found, as indicated in the memorandum referred to, that there is a great scarcity of researchers in Canada. The number is greatly less than the Dominion requires in order to develop scientific research, not only in the Universities but also more especially in the utilization of the natural resources of the country.

"It is true that a similar dearth obtains in the United States and Great Britain. Again and again have the British and American Research Councils referred to this scarcity and they are promoting measures which will, in the end, meet the situation to a certain degree. At present, what difficulties they encounter are shown in an extract of a letter addressed by the Chairman of the National Research Council of the United States, Professor H. A. Bumstead, to the Chairman of the Canadian Research Council, which is as follows:

"'The difficulty of getting properly qualified research men, which you refer to in the last paragraph of your letter, is as conspicuous in the United States as you say it is in Canada. Money, apparatus and laboratories are easier to get than men. Almost everybody recognizes this, including men in the industries who have had some experience of the methods and results of research. Our Council has this problem very seriously in mind and we have some plans under consideration for attempting to capture a larger number of promising undergraduates in our universities. It is, however, exceedingly difficult to say whether or not much can be done in this way. When all is said and done, material returns for scientific research are so much less than for business that it is not easy to persuade young men to enter upon it as a career. The recent campaign for increased salaries for professors has accentuated the feeling among the people of the country that science and teaching are poverty-stricken professions; this increases the reluctance of parents to allow their sons to go into them. I had two instances of this in my own classes last year. It is, I think, one of the directions in which it is most necessary that missionary work should be done.'"

"In Canada the difficulty of promoting the development of scientific researchers is, in one respect, greater than it is in the United States and Great Britain. Our universities are young. They have inadequate endowments and they cannot provide the Studentships and Fellowships necessary which will permit young graduates in science to train for a career in research. They also have not sufficient staffs in science and adequate accommodation to train all the students required. Further, the energies of these universities have been expended in providing the instruction to students to qualify for the ordinary degrees. The degree of Doctor of Philosophy, which postulates on the part of the recipient a training in the methods of research, has been awarded to less than forty students of science in the whole Dominion in the last twenty years, and yet the Alumni of these universities, it is estimated exceed 30,000 in number. The lure of the American universities offering a very considerable number of Studentships and Fellowships has attracted Canadian students of ability to them for the training in research which such

students require, and the result is that a considerable portion of those so lured away have not returned to the Dominion and fill positions of distinction in American universities and in the Research Laboratories provided by industrial firms in the United States for their own needs.

"What is immediately necessary is an earnest and sustained effort to provide courses in research in universities of Canada which will attract students to them and permit them to receive the training which a career in research demands. For the next few years at least one hundred graduates annually should complete such a training in order eventually to overtake the demand for researchers which will develop in the immediate future. If the National Research Institute is founded, and there is a prospect of this during the next Parliamentary session, at least a staff of four hundred or five hundred researchers will be required, and if they are not trained in Canada, or if Canadians do not receive such training either in Canada or the United States, the staff may be composed, in large part, of qualified men imported from abroad. The industries in Canada in the near future will also require scientific researchers to staff the Research Laboratories of the Trade Guilds for research which will be more or less in association with the proposed National Research Institute. If such researchers are not trained in Canada they also must be imported, an undesirable contingency and to be justified only on the plea of necessity."

Ladies and gentlemen, that is a perfectly plain, straightforward, businesslike statement of the needs of Canada as far as the human element is concerned. Knowing Canada as well as I do, I am confident that the laboratories, with the necessary equipment and apparatus, will be forthcoming supplied either by public funds or through the generous impulse of individuals. With regard to obtaining the trained men I have no immediate solution to offer. I have no doubt, however, as to the ultimate result.

May this be my message to you, to the members of the Royal Canadian Institute, the oldest institution for the promotion of science in the Dominion of Canada. Your record is one of which you have the fullest reason to be proud. You have already accomplished great things and the success and conquests you have achieved in the past will, I know, be an inducement to you to make further efforts in the future. It would not be fair, however, it would not be right, that the solution of a problem, which goes to the very heart of our existence, should be thrown upon you alone. The experiences of war and peace times combine to show that no nation can continue to live which does not train its men and women to use to the greatest advantage those resources with which it has been blessed. Our task in Canada to-day is to train our young

people so that they may be in a position to realize on the natural resources of the country. It may be said that I am suggesting expenditures of money or asking for subscriptions. What I am asking for, however, is not expenditure of money. I am asking you to make the best investment you ever made in your lives. The opportunity is in your hands. Your children are certainly not behind those of any other country. Personally, I have come to the conclusion that I have never come across a brighter child than the native Canadian child. You have a population whose individuals, with proper training and adequate inducement offered to them, are capable of holding their own scientifically with the citizens of any civilized country in the world. You have the human asset; you have the natural resources.

In the beginning of my speech I mentioned my ancestor who tucked himself away in his stable and mucked away over his experiments. With you practical questions are dealt with in a practical way. As a nation you have proved yourselves in war and in peace capable and qualified to deal with your problems.

For the problem of which I have been speaking I offer no solution. You yourselves must find the solution, as you know, and you are working on it. I can only wish you Godspeed in the great work which you are doing, and I feel confident that the success which you have achieved in the past is only a guarantee of greater success which you will achieve in the future. (Applause.)

SCIENTIFIC RESEARCH AND PUBLIC HEALTH

By W. H. Howell

Henry Adams in his Education complains with some feeling that life in our generation has acquired an acceleration that is disturbing and discouraging. The discoveries of Science that have given mankind such wonderful control over the forces of nature and have added so greatly to the comforts and conveniences of life have increased also its complexity and speed. Most of us who have passed middle life will agree that living in our day is a strenuous affair, that existence is not a placidly flowing stream but a rushing torrent. With our telegraph and wireless and rapid means of locomotion we triumph over time and space, but by the same tokens these forces that we have called into existence have set for us a more exacting standard of performance to which we must conform. A leisurely comfortable pace means failure.

Adams thinks that this acceleration in living is increasing something after the manner of the velocity of a comet approaching perihelion, and, he seems to suggest that the comet will sweep round the centre of attraction and plunge outward with ever decreasing speed to an aphelion of dark ages and shattered civilization.

The same idea is expressed in different ways in the writings of others of our contemporaries. Saleeby, for example, in one of his sprightly essays warns his fellow-countrymen that as a nation their mental tempo is too slow—that big strong slow nations like the big strong slow animals of the quaternary period will suffer in competition with swifter, more responsive peoples.

We must admit the general premise that the pace now is more rapid than in former days and that it tends to increase in accordance with some as yet unknown law of acceleration. We may accept the conclusion that this condition has come upon us as a result of our increase in knowledge and we may even agree that in proportion as our mastery of nature grows the complexities of living must be multiplied. But it will avail us nothing merely to protest like the Preacher that "he that increaseth knowledge increaseth sorrow". If greater knowledge brings greater sorrows it brings also larger opportunities for happiness and usefulness and we should apply our intelligence to minimize the ills and magnify the good. Reflections of this kind suggest themselves whenever one considers matters of public health. Civilization has tended constantly to increase the density of population, to change the mode of living from the

rural to the urban type, to convert a dilute solution of humanity into a concentrated solution. The change is accomplished always by an increase in the comforts and conveniences of living, but at the same time it tends to magnify the dangers to life from disease and accident. Disease spreads more rapidly the closer the contact between man and man, and the rate of mortality in spite of the most improved modes of sanitation is greater in the cities than in the country districts. So also our new rapid means of locomotion are accompanied by fearful losses of life from accidents. The omnipresent automobile is slaying its thousands annually; at such a rate in fact that if not checked it bids fair to become one of the major causes of mortality. We can not well escape such consequences, we must learn to provide against them by wise laws and especially by increasing our knowledge of the order of nature. Under present conditions apparently our margin of safety is uncomfortably small. As soon as circumstances arise that interfere with the stability of government or put any unusual stress upon the customs of civilization the equilibrium that we have succeeded in establishing is seriously disturbed, pestilence and famine raise their ugly heads like weeds in a garden. We all know that such a condition is upon us now. As an aftermath of the great war there has developed a wide spread disorganization of society, and immediately the old hostile forces of nature spring into action and threaten the well being of mankind. It becomes necessary to organize official and volunteer agencies of all kinds to stem the rising tide of suffering and disease.

Earnest spirits the world over have hoped that human intelligence may devise some plan whereby wars may be prevented or controlled to some large degree, not alone for the direct saving in life that would be effected, but for the sake of protecting human society from the frightful strains occasioned by wars which endanger the stability of the whole structure.

Those who have attempted to set into action a League of Nations to prevent wars among men have not overlooked the fact that mankind as a whole is constantly at war with nature, and that in the one case as in the other it is desirable to pool our knowledge and intelligence so as to discover the most effective means of promoting the common good. By organization and co-operation we may utilize our combined resources to offset the advantages that arise for nature out of the increasing complexities of civilization. It is a wise provision of the covenant that it arranges for the establishment of an International Health Organization. It is to be assumed that an organization of this character together with the great unofficial international health agencies, such as the League of Red Cross Societies will not be hampered in their work by selfish national-

istic ambitions, for in the warfare against nature we are all allies and our common interests will tend to strengthen the alliance more and more as we come to appreciate the nature and strength of the forces arrayed against us.

The general status of our relations with nature may be summarized in this way. Man as an organism must adapt himself to his environment. Speaking in very general terms, the environment may be described as biological and physical. Under the designation biological environment I would group man's relations to other living things, including his fellow man. But the living things in which we are chiefly interested from the point of view of public health are those small organisms that live on or in our bodies and which as a consequence of their parasitism give rise to dangerous or fatal diseases. Some of these organisms, it is true, may be our friends, but for the most part they are competitors and enemies—and our relations with them are best described by the familiar terms of human warfare. In our operations against them we must use methods both of defense and offense. The notable defensive agencies are those that have been developed without our conscious assistance by natural selection. They exist ready formed in the body. When invading organisms gain access to our bodies they are in part bodily captured and destroyed by a certain group of cells designated as phagocytes, or their power for evil is met by the automatic production in the tissues of antagonistic substances of various kinds which immunize the body against the activity of the special invader. This power of the tissues to create a special immunity is a marvelous reaction in its delicacy and its complexity. The chemistry of the processes involved is far beyond the ability of the scientist to understand or to imitate. But we know that the power exists, a special branch of preventive medicine has been organized for its study and carefully trained scientific workers in many laboratories are devoting their time and energy to its investigation. Nature offers here a problem of great intricacy and we want to know all about it for two reasons. First, simply to widen our knowledge, for Science, as Clifford put it, is interested in "everything that is or has been or may be related to man". Second, for a utilitarian reason. Altough the processes of immunity work automatically without our conscious assistance, it is obvious that if we understand them we may greatly increase their field of action. We can take this defensive agency developed through the blind processes of nature and improve it to who can tell what degree. A beginning has been made. Everyone knows of the successful use of the antitoxins for diphtheria and tetanus and of the wide spread benefits in the way of prevention obtained from vaccines of various kinds. But it is only a

beginning and we have every reason to believe that there are immense possibilities in the future. To realize these possibilities we need a large number of trained scientific workers with facilities and leisure for intensive work. There is no lack of young men and women who would be willing or even eager to enter upon a career of this kind both on account of the intrinsic interest of the work and on account of the great service it would be to humanity. The difficulty in pushing the matter forward with the proper speed lies in the financial support required. The universities and medical schools are contributing in proportion to their limited means, and occasionally gifts from private benefactors help the good work along, but naturally we look to governmental agencies for the chief support in a matter affecting so directly the public good. The obligations of government in safe-guarding public health have been recognized only in modern times. The passage by Parliament of the Public Health Act of 1848 is perhaps the first decisive step in this direction. Since that time great developments have occurred. The Government has made greater and greater efforts to protect the health of the people, but its efforts have been confined largely to the application of knowledge and methods already discovered. The importance of supporting scientific investigations looking forward to new discoveries has not been recognized by legislators as a class, and presumably will not be so recognized in democratic governments until the intelligent part of the community becomes convinced that money spent in such ways is a paying investment. At present we spend immense sums of the public money to protect ourselves from the aggressions of our fellow man. If the time comes when this will not be necessary then no doubt we can pay more attention to our troubles with our non-human enemies and provide the funds for greater protection against their ravages.

Carrying out my militaristic analogy let me say a word about the offensive side. It is quite possible in this contest to carry the war into the enemy's country. The kind of campaign that can be developed is clear enough and we have every reason to believe that it will be successful, for on our side we have the advantage of intelligence, the mind of man capable of understanding and using the forces of nature, while on the other the chief weapon is mere force of numbers, the incredible fertility of the lower forms of life. The insects that infest our bodies, flies and mosquitoes, fleas, ticks and lice are directly or indirectly carriers of disease. It is easily possible for us to find out all about their structure, habits and life histories and thus put ourselves in a position to control or destroy their fertility. Medical Zoology has become a specialized branch of investigation cultivated in all of our schools of public health

and especially in the laboratories engaged in the study of tropical diseases. It is a subject that at present is largely in the morphological stage, but later it will widen out into the investigation of the functional sides and if only adequate support can be found to provide workers and facilities we may look forward to a practically complete mastery over such forms of life so far as they are inimical to our lives or our possessions. What can be accomplished in this direction is illustrated by the splendid triumphs of bacteriology. The brilliant beginning made by Pasteur has been followed up and extended by a host of workers. Their combined labors have enabled us to obtain a measurable control over many diseases which formerly spread death and desolation over the entire world. The work is very far from being completed. There are still disasters like our recent epidemic of influenza before which we are almost entirely helpless. But no one can doubt that the systematic application of the methods of investigation which we now possess will eventually give us control over this and similar diseases due to the action of living organisms. The labor involved is great. One can get an idea of what it must cost by looking back at the history of Bacteriology. This history is not long for the subject came into existence only a generation ago. But if one reviews the great volume of literature that has appeared in this subject during the past forty years, and if further one pauses to reflect upon the months and years of labor that have gone into the preparation of each of the papers in this long list, he arrives at a conception of the enormous expenditure of human energy and intelligence which has been necessary to win for us our present position of advantage. We must be prepared to do much more. We of this generation are the beneficiaries of the labor of those who have gone before and in our turn we must do our part in handsome fashion. It is not sufficient for us simply to make use of the knowledge handed down to us, for great and important as it is, it is nevertheless incomplete. We must know more—we must multiply our laboratories and workers and push our investigations along the lines that have been so successful in the past. A second Pasteur may or may not be born, the control of such events is not in our power, but what we can do if we put our minds to it is to create a large body of workers. The additive labor of many second rate workers in science is often equivalent in importance to the output of a single genius of the first order.

I have referred so far only to our relations to the biological environment, but hygiene is equally concerned with our relations to the physical environment. Under this term I would include all those physical and chemical forces that react upon the body from within and from without. The maintenance of health requires an unending series of adaptations to changing conditions. These adaptations are carried out with aston-

ishing success and for the most part without any voluntary guidance on our part. The mere fact that the machinery runs so well through so many years is a demonstration of the completeness of the physiological adaptations. But the more one learns about the delicate mechanisms and adjustments of the body the more he will be inclined to sympathize with Stevenson's point of view founded on personal experience—"And what, says he, pathologically looked at, is the human body with all its organs, but a mere bagful of petards? The least of them is as dangerous to the whole economy as the ship's powder magazine to the ship; and with every breath that we breathe and every meal we eat we are putting one or more of them in peril". It is not quite so bad as that. We know from experience that sudden explosions in the economy are not to be feared. We can rely upon the mechanism keeping intact under ordinary conditions for a certain period of time with somewhat the same confidence that we have that the earth will stick to its orbit and not take a tangential dive into outer space. A timid person might work up a scare with reference to that operation of nature also if he once gave himself up to the possibilities of things going wrong.

But while experience teaches us that the machinery is not likely to go to pieces all at once we know that it does break down in places very frequently. In later life particularly these failures in adjustment or adaptation thrust themselves disagreeably upon our attention. Slight deviations from the normal that at first seem to be of little importance grow into serious pathological defects which must be treated by the methods of medicine or surgery. The body must grow old of course. We accept senescence as a law of our being and in the long run senescence may be regarded as a gradually developing loss in the power of adaptation of the tissues to their internal environment, an increasing imperfection in the processes of nutrition; but by unhygienic living, by deliberate or ignorant disregard of the rules of health, we can bring about a premature disruption of one or more of the delicate adjustments of the body. A perfect system of preventive medicine would detect these deviations from the normal at the very beginning and would correct them by the application of hygienic measures. Sir James MacKenzie in a recent address before the Pathological Club of Edinburgh laid great emphasis upon this idea. Ordinarily when a patient gets into the hands of the consultant or the hospital physician things have gone too far for simple hygienic treatment, recource must be had to surgery or drugs. MacKenzie thinks that it is the special duty and opportunity of the practicing physician and particularly the family physician to investigate these troubles in their incipiency at a time when mild hygienic treatment may restore the normal status. Every one will admit that

this is the ideal thing to do, but it takes little consideration of the subject to make us realize also that it is a very difficult thing to do. To detect and interpret a minor deviation from the normal by the aid of subjective or objective symptoms is in itself a most intricate problem, when we remember the long period of time which may intervene between the initial symptoms and the appearance of the outspoken physical signs that reveal their significance, and when we remember also that the correlations thus indicated must be established by a large collection of cases. But were this much accomplished and were it possible to give a precise interpretation to early symptoms we should still be at a loss as to the proper hygienic measures to be adopted for the restoration of normal conditions. For the sake of an example let me use one of Mackenzie's illustrations. Hardening of the arteries, arterial sclerosis, is a frequent defect in middle and late life. Even when it does not shorten life prematurely it interferes seriously with the ability of the body to meet the ordinary demands of living. When the condition has advanced so far as to be recognizable by obvious physical signs it is too late to deal with it satisfactorily. Its progress may be blocked by rigorous changes in the mode of living but it may be doubted whether any treatment can be devised that will restore completely the *status quo ante*. Suppose that by careful observations on blood-pressure or by other means we could detect the earliest stages of this trouble, long before it gave the patient any serious inconvenience. What remedial measures could be suggested? I do not think that at present we have sufficient knowledge to be sure of the answer to this question. The physician by long continued observations and the use of the laborious method of trial and error might finally hit upon the right solution. But a shorter and surer method of reaching this same end would be to turn the problem over to laboratory investigators Let them determine which of the many abnormal conditions to which the arteries are subjected is responsible for the beginning of the trouble. Once this is determined and probably only after it is determined will it be possible for us to protect ourselves with any certainty from the development of this particular defect. What is true of this tissue is applicable to most of the other tissues and organs of the body. We are as a matter of fact very ignorant in regard to what might be called the rules of right living, that is to say the kind of living that would maintain the functions of our body at the highest standard of efficiency. The working out and formulating of these rules constitutes the main objective of so-called personal hygiene. This term I fear has no very high place in the public estimation. The subject in fact has been somewhat discredited by the kind of literature that has been given to the public in its name. Part of it has been written by very ignorant

persons who have not hesitated to advertise themselves by publishing most foolish and fanciful methods of preserving or regaining health. But to my mind more harm has been done through the misdirected efforts of propagandists whose zeal is greater than their knowledge, and who in their effort to get something across to the public which in their eyes seems good are guilty of much virtuous lying. Personal hygiene to most persons means something dreadfully bromidic about brushing the teeth, or daily baths, or else it implies some one or other of the many novelties in health panaceas which like bad pennies keep constantly turning up when something better is needed.

In reality personal hygiene is a subject of the greatest importance which has been much neglected and which calls for scientific study of the most exact kind. Preventive Medicine and Sanitation have succeeded in adding a number of years to the average life. The expectation of life at birth has been increased during the last fifty years by 10 years years or more, largely through control of the infectious diseases of early life. But most of us would place an equal or higher value upon the kind of knowledge that would enable us to avoid those disabling defects and illnesses that bring about chronic invalidism or impair our physical efficiency, without killing us outright. The information that we have at present is derived in part from the accumulated experience of life, the results of a long series of experiments on the trial and error principle, and in part from mere *obiter dicta* of eminent physicians which are not based on sound scientific evidence and have therefore a very doubtful value. Science has knowledge and methods which if applied intelligently should add something of real importance to our inherited traditions in regard to the rules of living. An instance in point is found in modern work upon the vitamines. The study of a pathological condition, the oriental disease of Beri-beri, furnished certain ideas in regard to diet which have been extended by investigations in various directions until finally there has emerged the important truth that three, perhaps more, mysterious substances, grouped under the term vitamines are essential constituents of our food. A few years ago we felt that Science had uncovered all the facts necessary for the rational control of diet. The composition of the foods in proteins, fats, carbohydrates and salts and the energy value of these constituents in calories seemed to comprise all of the essential data for such calculations. But we know now that this was a hasty conclusion. In laboratories all over the world inquiries are being pushed rapidly in regard to the number, character and occurrence of the vitamines and this new knowledge will make itself felt, indeed has already made itself felt in the dieting of both the well and the sick. Discoveries of this kind bearing upon the daily conduct of life may arise

at any time from serious investigations in any of the biological or physical sciences, but they are to be expected mainly from work in the physiological sciences. In all schools of Hygiene and Public Health there should be physiological departments organized with this point in view. In recent years the triumphs of bacteriology in gaining an understanding of the infectious diseases have been so striking and their practical application has been so important that, for a while, the physiological opportunities have been overlooked. Schools of Hygiene have been chiefly schools of bacteriology and its related branches. In our new school at Baltimore recently established I am glad to say that we have borne in mind that work in public health has in the last analysis two great objectives, the control of communicable diseases on the one hand and the preservation of normal health on the other, and provision has been made for instruction and research along both lines.

The few thoughts that I have presented so briefly and imperfectly have been intended as a plea for the importance of scientific research, particularly in its applications to public health. For many years the practical bearings of science upon our daily lives have been obtaining more and more recognition. The late war has served to demonstrate this relation and has even forced a sort of official acknowledgment of the necessity of governmental support of scientific research.

We may anticipate therefore an increased demand for trained investigators, but in order to meet this demand it will certainly be necessary to improve the outlook for a scientific career. The work of investigation, of scientific discovery if you will, is the most difficult task offered to the human intellect. We can not afford to rely simply upon chance for the selection of men suitable for such work. Nor should we assume that impulses of idealism and altruism will drive into this career the minds most capable of penetrating the dark secrets of nature. High ideals unfortunately are no guaranty of high intellect. We should make a deliberate effort to discover scientific aptitudes and to hold out inducements that will attract the best minds. In some of our scientific societies we have discussed this matter with reference to the ways and means most likely to bring together the career and the mind adapted to it. Among the projects proposed one that seems to me to be most hopeful is to establish a popular scientific journal for the young, rich in illustrations and written for and edited by our most gifted men and women. We know perfectly well that the material we have to present is thrillingly interesting. This is a bold statement to make, for Heaven knows that much popular scientific literature is bone-dry, and what goes under that name in many of our journals is a disgrace to the writers and a sore affliction to the Scientist. But it can be done differently. Huxley

could write about a piece of chalk in a way to hold spell-bound any normal being young or old. If we can develop or find some men or women with the knowledge and gifts of expression of a Huxley or a Tyndall we shall be able to bring before the young generation the kind of literature that will reveal the scientific mind to itself—that will search out the young Miltons of science and save them from a mute inglorious end. And when they are found we must help them on the way by providing encouragement and removing obstacles. Heretofore the financial return to the scientific worker has been inadequate, hardly sufficient for a decent livelihood. This difficulty has been met in part in recent years by the creation of better paid positions in the industries and in the special research laboratories, but an unfortunate characteristic of this development is that it makes no provision for the training of young investigators. Now as formerly the new recruits in Science are educated in our universities. To make this training effective the universities should be officered with our best scientific talent, and unfortunately there is an increasing difficulty in maintaining a high standard in this respect. The salaries offered by the universities are relatively small and the facilities and opportunities for research work are not usually so complete as in the industrial and the special research laboratories. There is a real danger therefore that our best men will be drawn away from the universities, and in this way the highest development and growth of research will be impeded. Another defect in the university positions lies in the complexity of the duties thrust upon the professor. Frequently he is overloaded with routine teaching and in addition is required to give much of his time to administrative details and perhaps to outside service. Work of this latter character is easy enough and pleasant enough but it tends to paralyze investigation. Research requires the best of a man's thoughts and much of his time. But so soon as a man arrives at some eminence in his subject and is called to the headship of a department, he finds that much of his time and attention must be given to business details and to what Army officers call paper work. His leisure time for thought and invention is taken away, and if he surrenders too completely to these demands he gradually undergoes a process of deterioration. There is such a thing as the unmaking as well as the making of an investigator; the organization of our universities at present is so constituted, it seems to me, as to offer conditions favourable to the making of young investigators, but favourable also to the unmaking of an experienced investigator if he happens to be the head of a large department.

In the industrial laboratories and the laboratories of special research investigation is the principal or the sole duty—in the universities on the other hand it is a secondary duty, something to be attended to between

times. Some teaching is an advantage to an investigator,—probably a great advantage, it keeps him from becoming too specialized and narrow in his subject, but much of the administrative work is a pure waste of energy and time with no compensatory advantages. And the worst feature of it is that it constitutes the badge of authority. Because he is the head the professor is the last court of appeal in all arrangements connected with the running of the department, and it is astonishing how numerous these details are and what a quantity of time it takes to set them straight. If the professor is good at such things he is in a fair way to be lost as an investigator—there is no end to the committee meetings and consultations and conferences to which he will be invited—all of which is very agreeable and useful but terribly destructive of time and concentration of thought. Another characteristic of scientific investigation that operates against its popularity as a career is the very natural difficulty of getting the public to understand its results. Public opinion can make a favourable or an unfavourable atmosphere for the development of any kind of human activity. I do not know how it is here but in the United States I should say that in general the atmosphere is unfavourable to a career in science. The scientific worker as a rule is held in small esteem by men of affairs, partly no doubt because he earns a small income and therefore makes a small show as regards the externalities of life. We are not so far advanced as to make many exceptions to our general rule of judging a man's success and ability by the financial return he enjoys. But the main difficulty doubtless lies in the technical character of his work which makes it more or less incomprehensible to any one but a specialist. Scientific discoveries are not usually amenable to an immediate practical application with an assured money value, and yet that is quite generally the standard by which their importance is estimated by the public. I recall that one of our large universities determined upon one occasion to seek for an increased endowment. The raising of the money was turned over to one of the trustees. The plan that he evolved was to construct a list of the discoveries made in the various laboratories. He intended to take the list to a certain individual and by its aid to convince him that it would be a good investment to add to the endowment of an institution showing such useful productivity. The plan did not work out well—in fact it did not work out at all. The trustee made the rounds of the laboratories and the professors explained what they had accomplished in the way of scientific discoveries. It was a very creditable record. Much had been done in the advancement of knowledge, but it did not meet the main purpose of the inquiry, for there was little that could be shown to have had an important application to the necessities or comforts of

life. And yet almost every one will admit that the great developments, in the business world and in the medical world originate in such technical discoveries. The public must learn to appreciate that fact and to accept the valuation of scientific results from the hands of the experts and specialists who are in a position to make an intelligent judgment. Take the case of electricity; consider the extent to which it is used in the commerce of the world at present, and the amount of capital invested in it in one way or another, and then think of its small beginning and the long period of development before it was ready for the world's use. It was forty years from the initial observations made by Galvani upon the cause of the mysterious twitching of frogs muscles brought into contact with pieces of metal, before Faraday made his great discovery that a magnet brought near a coil of wire will arouse in the latter an electrical current, and forty years or more after Faraday's discovery before any really important practical use was made of it. We know now that Faraday's discovery was the beginning from which has sprung all of our great electrical apparatus for generating power. Faraday knew and his scientific contemporaries knew that he had made a great discovery, but who could tell then how great its practical value would be. You remember the story told about him when demonstrating his result before a public audience. One of the ladies in attendance said to him—This is no doubt a very interesting experiment Mr. Faraday, but what use is it? "Madam", said Faraday, "what use is a new-born baby"? The answer was most appropriate. New discoveries in Science have potentialities of usefulness in the practical affairs of life, but whether or not these potentialities will be realized can not be fore-told.

The duty of the Scientist is to discover any new truths that he may. Every such truth is bound to have some importance and some of them will be of the utmost value to the world. Only by this method can we gain that more perfect knowledge and control of nature's laws which is indispensable to the advancement and preservation of our civilization.

PHYSICAL PROBLEMS WHICH ARISE IN STUDYING THE INFLUENCE OF ATMOSPHERIC CONDITIONS UPON HEALTH

By A. Norman Shaw, D.Sc.

(Presented by Dr. A. S. Eve, C.B.E., F.R.S., F.R.S.C.)

(Read May Meeting, 1920.)

This article is written in order to plead for an increased interest and for a larger number of workers in the subject under discussion. The field of investigation has, indeed, such an important bearing on the health of the community, it contains so many unsolved but yet not too formidable problems, and there have remained almost undisturbed in the customary treatments of the matter, so many fallacies that it was considered of importance to call further attention to the whole question, to enumerate some of the simpler problems, and to discuss briefly a few of the difficulties which have been responsible for lack of progress in the past.

The study of the atmospheric conditions which determine human health and comfort, involves physiological, bacteriological, chemical and physical problems. The most general and practically inclusive physical problem which arises, is to determine the influence of variable surroundings upon the loss of energy from a heated thermo-regulating mechanism which possesses an outer hygroscopic surface of variable quality. It is thus closely allied to many other familiar problems which involve questions of radiation, convection, conduction and evaporation.

The reactions of the different types of external changes on the internal animal mechanism are varied in character; and it is very important to note that the operation of the regulating mechanisms requires the special stimulus of a certain amount of continuous variation in the external conditions, without which the performance of their proper functions seriously deteriorates. It is evident therefore that a part of the main physical problem must be considered with reference to the physiological processes which are involved in the internal thermo-regulation. The influence of the chemical constitution of the air, and of the bacterial content likewise must be considered in conjunction with physiological data, but on the other hand although obviously affected by the physical conditions, they may quite logically be considered and investigated as

separate problems. It is, however, now generally accepted that the influence of impure air in badly ventilated places, is within the limits of all ordinary occurence, almost negligible in comparison with the consequences of the purely physical conditions.

The examination of the various physical factors has been frequently confused on account of the failure to recognize that they should be considered along the lines of the general problem which was stated above. Until recently the problems were attacked almost invariably by considering the direct effects of altering successively the various conditions, but nearly always without paying sufficient attention to the accompanying or the induced compensations, some of which always took place within the internal mechanism and others of which might be produced by a readjustment of the external conditions.

Let us consider some very simple examples of this prevalent confusion. It is a common observation and may also be deduced from the statements in many texts of good standing, that a rise in external temperature accompanied by a decrease in relative humidity, must necessarily lead to an increase in evaporation from exposed surfaces. *This is not necessarily true*, even if the motion of the surrounding air is the same in both cases. The failure to grasp this elementary possibility at once, is apparently due entirely to a lack of appreciation of the fundamental quantities, and also to a noticeable vagueness very frequently associated with the use of the term relative humidity[1]. The factors of temperature and humidity with their general effects, have been familiar, but they have persistently been examined without proper reference to the whole of the problem in which their consideration is required.

It should have been obvious in this example that the higher temperature could be such that the accompanying decrease of relative humidity might correspond to an increase in absolute humidity or vapour pressure, thus producing a decrease in evaporation from any moist surface kept at a fairly constant temperature. There would be an increase in evaporation if the relative humidity were sufficiently decreased to indicate that the absolute humidity was also lowered. The question of variation in comfort when there was an increase or decrease in evaporation would depend on the fundamental quantity of total heat loss from the body. If there is a change in the cooling due to evaporation when the surface is moist there are usually changes in the quantity of heat received by radiation and by direct contact with the surrounding air. Considered separately the influence of the factors on comfort are generally obscure, but in terms of the general problem the interpretation is clear.

[1]See A. N. Shaw, *Relative Humidity*, Trans. Roy. Soc. Can. Vol. II, pp, 121-127 (1917.)

Sometimes an increased loss of heat from the body with the resultant impression of cooler conditions occurs when *both* the temperature and the relative humidity have risen. This is again quite understandable if we keep the general problem in mind. It may be ascertained that there has been a sufficient increase in the rate of air circulation to account for it; or there may have been a decrease in the incident heat radiation (*e.g.* as may often be found in passing from a room heated by good radiators to one heated by a hot-air system and indicated by a thermometer as apparently the warmer), or it may be found that the internal metabolism has been disturbed, so that less heat is conducted to the surface from within.

Another fruitful source of misinterpretation occurs in the direct consideration of hygroscopic surfaces. The temperature coefficient of evaporation of water from a hygroscopic surface is not the same as from a free water surface; there is usually a difference in temperature on each side of any hygroscopic surface which is not in equilibrium with its surroundings; and there is a simple sufficient condition that evaporation or condensation will take place until the absolute vapour pressures across the surface (or more correctly, across the equivalent thin heterogeneous layers) are equal in each direction. These three points have been overlooked or misrepresented to a surprising degree.

In illustration of this a case is known of a manufacturer who went to a great expense on supposedly expert professional advice in the duplication of the atmospheric conditions which were stated to be favourable for a particular process. The average external temperature and humidities were duplicated successfully, but it so happened that the average temperature of the substance during the drying and other processes was not duplicated; neither was the incident heat radiation nor the mode of air circulation. The result was that the artificial conditions of controlled evaporation and internal temperature differed nearly as much from those sought as did the previously uncontrolled arrangements.

Before going further,—although it is not the intention at this time to review either original work or the work of others,—attention should be called to the report of Dr. Leonard Hill in 1919, to the Medical Research Committee for National Health Insurance (published by H. M. Stationery Office, London) entitled "The Science of Ventilation and Open Air Treatment." In this extensive monograph there is presented a mass of original and also of collected data, which have been analyzed from the point of view of what has been called the main problem and which constitute one of the most advanced contributions on the subject. The work of the New York State Commission on Ven-

tilation (associated with the names of C. E. A. Winslow, D.D. Kimball, G. T. Palmer, F. S. Lee, J. A. Miller and others), and also of the Chicago Department of Health (under the direction of Dr. E. Vernon Hill), have appeared in numerous articles published by the American Journal of Public Health, the Journal of the American Society of Heating and Ventilating Engineers, the Journal of Industrial and Engineering Chemistry, Domestic Engineering, the American Journal of the Medical Sciences, the American Journal of Physiology and others. Some of these papers present an amount of elaborate investigation which should be reviewed most carefully by any prospective investigator. Further references are given at the end of this article.

As the purpose of this article is to interest and to attract more workers to a fertile field, a list of a few of the simpler problems pressing for attention is submitted below, together with the practical spur of some suggestions of procedure for several of them.

Problems

(1) The variation of vapour pressure with temperature for all the characteristic hygroscopic substances should be thoroughly investigated. These data would be of great value in the development of several types of hygrometers, in the study of evaporation from skins and plant surfaces, and in the determinations of the moisture content of certain materials.

It is suggested that thin specimens of a given hygroscopic substance be prepared with a very large surface per unit volume. A calibration should then be made of several of them for changes in weight under the influence of varying external vapour pressure,—care being taken that the temperature of the substance is the same as that of the surrounding air, whenever a weight is recorded. This calibration can be made conveniently by suspending the specimen successively in a series of closed jars each of which contain at the bottom a diluted deliquescent salt of previously ascertained vapour pressure. The weight can be obtained with a delicate balance when equilibrium is reached, by means of a wire passing through a suitable long tubular hole in the top of the jar, which should be sealed between readings.

One of these specimens will then constitute an accurate calibrated hygrometer which will exhibit the same phenomena and the same peculiarities as the material to be examined. If it is then suspended in a jar which is kept at a constant temperature, and connected by a tube to another jar containing a similar specimen, it should be possible by varying the temperature of a bath round

the second jar and recording successively the equilibrium weights of each specimen, to determine the variation of the vapour pressure with temperature in such a manner that the usual errors are either eliminated or readily determined.

The method of calibration has been successfully applied by the writer in the case of thin films of sulphuric acid, thin paper containing diluted calcium chloride, and thin paper containing diluted phosphorous pentoxide.

(2) The variation of the internal temperature of small volumes of hygroscopic materials, with difference in vapour pressure between its surface and the surrounding air, should be investigated. This is important because in many cases there is a surprising temperature variation during a very short interval of time after a sudden change in external vapour pressure has been produced. The data may also be utilized for purposes of hygrometrical determinations in small confined spaces.

A thermo-couple method utilizing the type of hygrometer described above, should lead to definite results. This variation has been observed qualitatively in the case of bundles of hair, tobacco, fine shavings of wood, and small piles of powdered salts, but no systematic investigation has apparently been attempted.

(3) The influence of the average irregularity of a hygroscopic surface, on its vapour pressure requires investigation. This effect is appreciable in the case of hard surfaces which may be found either smooth in one instance, or covered with sharply peaked irregularities in another.

A series of observations with the microscope on the rate of evaporation of curved surfaces of hygroscopic solutions, of known concentration and of various curvatures, could be obtained under known conditions at the end of capillary tubes for the purpose of comparison with the elementary theory of the influence of curvature on vapour pressure. A record of the variations in vapour pressure from coarse surfaces which absorbed the same solution, could then be interpreted. Great care is necessary in all experiments of this type to eliminate or to control the effects of incident radiation, and irregular convection.

(4) With most systems of ventilation "convection" heating in buildings leads to a condition where the air is warmer than most of the surrounding objects, in "radiation" heating the converse is usually the case. As the latter condition is probably the more healthy, and as the former condition is the more prevalent in this country, there is obviously need for development.

In the design of hot-water radiators now in general use, the ratio of the heat supplied by convection to that supplied by radiation varies considerably with surrounding conditions. A thorough investigation of this question would be of value. In the past it appears that many of the improvements have been limited by economic pressure merely to modifying existing systems progressively. The systematic testing of a series of radical designs is required. Theoretical considerations lead to the suggestion of many unfamiliar types.

A simple method of investigating the loss of heat from a radiator in such a way that many of the usual difficulties are avoided is as follows. Fill a small model of the radiator with cold water and fit it with thermometers; place it in a large bath of hot water kept at constant temperature and obtain a "warming up" curve; do the same in a large enclosure of hot air kept at constant temperature; place the model in a jar and do the same experiment before and after evacuation of the jar; repeat the series with the temperature conditions reversed and get "cooling" curves; examine also the effect of increasing the natural convection in the enclosure. The analysis of the "cooling" and "warming up" curves should lead to more accurate results than are to be obtained from the application of the available formulae and published data. The effect of the nature of the surface on the emissivity could be studied at the same time. Engineering tables give most conflicting data with regard to the influence of the surface.

Experiments of this character can be developed to check formulae of general interest and importance. Information regarding the temperature coefficiencts of radiation and convection could be obtained, and the objective reality and the general characteristics of the special films of air which are supposed to adhere to the surfaces of warming or cooling bodies, could be determined with the aid of small thermocouples. The design of methods of procedure which lead to the elimination of external losses from consideration, should be the chief concern in such experiments.

(5) The influence of small atmospheric eddies and general turbulence on the validity of the theoretical and of the empirical formulae which are applicable to convection problems, requires extensive examination. The interpretation of such instruments as the katathermometer and the caleometer under turbulent open air conditions is still in an unsatisfactory state, and it is of importance that the data obtainable with such instruments which are so valuable in the quieter conditions, should be ascertained more definitely

for open air conditions. The determination of corrections for incident radiation, and surface emissivity constitutes one of the chief difficulties in the work.

A radical simplification in the design and operation of these instruments is also essential before they can pass into the general usage which they deserve on theoretical grounds. An instrument which virtually requires the performance of an experiment in order to obtain a reading, or which requires skilled attention, is very difficult to introduce into customary usage. Readings must be available instantly on a scale or dial, and the expense must not be prohibitive. Although this particular field of work as a whole is difficult both theoretically and experimentally, there are many pieces of information that are worth securing and which should require little more than a kata-thermometer, a pitot-tube, an electric fan, an electric heater, an aspiration hygrometer and the facilities for enclosing the instrument in vacuo.

(6) Devices which when desired can be made to insure a more definite avoidance both of "*monotonous*" conditions, and of "*monotonous*" variations in the large calorimeters used for metabolism experiments, are required in conjunction with the means of knowiug exactly what conditions are being produced. At present the results of the best investigations are somewhat in disagreement, very largely on account of uncertainty about this matter.

(7) The theory of the atmometer and its relation to the cooling and evaporative power of the surrounding atmosphere on other surfaces, requires considerable amplification with reference to the points which have been indicated in regard to hygroscopic surfaces.

(8) The influence of the atmospheric conditions on the electrical state of surfaces and small particles, requires more attention. The circulation of dust particles is very greatly influenced by the electrical charges which they obtain in dry moving air. The critical conditions which lead to extreme static charging of surfaces, are not completely understood, and in many manufacturing processes are a source of danger. Very little attention has been paid to the possible reaction of the surface electrical conditions which are created in turbulent arid atmospheres on the subcutaneous nerve endings. Ionization experiments alone will not suffice in dealing with such problems; questions of surface electrical conductivity arise and lead one at once into the large field of problems which nvolves the simultaneous consideration of the surface electrical conductivity, the concentrations of conducting medium, and the surrounding conditions.

(9) One definite problem along these latter lines, is the development of a precision electrical hygrometer. The writer has developed electrical hygroscopes, based on the variable conductivity of thin films of hygroscopic solutions exposed to the atmosphere, which indicate changes in humidity of one hundredth of one per cent., but owing to ignorance about the behaviour of the conflicting factors, and the experimental difficulties involved in conductivity measurements of this character, they have not yet been developed further.

Bibliography

The bibliography dealing with these topics is very large and involves nearly one hundred papers. The following articles by Leonard Hill form an admirable introduction, present an almost complete survey, and develope or initiate some of the most important contributions to the subject. As they include also a very extensive list of references practically covering the whole ground, it is unnecessary to repeat again the bibliography in full.

Hill, L. Griffith, O. W., and Flack, M. "The Measurement of the Rate of Heat-Loss at Body Temperatures by Convection, Radiation and Evaporation." *Phil. Trans. Roy. Soc. Lon.* B., vol. 207, pp. 183-220. (1916.)

Hill, L. "Atmospheric Conditions which affect Health." *Quar. Jour. Roy. Meteor. Soc. vol. 45*, pp. 189-237. (1919).

Hill, L., and Hargood-Ash D. "On the Cooling and Evaporative Powers of the Atmosphere." *Proc. Roy. Soc. Lon. B.*, vol. 90, pp. 438-447. (1919.)

Hill, L. "Science of Ventilation and Open Air Treatment." Report to Medical Research Committee for National Health Insurance (Pub. H. M. Stationery Office).

The reports and various papers under the auspices of the New York State Commission on Ventilation, and those of the Chicago department of Health, present the most recent American contributions to the subject, and also give further useful references. The final analysis and the correlation of these extensive investigations are eagerly awaited. Careful reference should be made to the journals listed on page 4 and also to the Monthly Weather Review for the past six years, as a very large number of their articles have either a direct or an indirect bearing on this work.

The recently published text-books, "Manual of Meteorology," by Sir Napier Shaw (Cambridge University Press), "Physics of the Air," by W. J. Humphreys (Lippincott), and "The Principles of Aerography,"

by A. McAdie (Rand McNally), should be consulted for additional references and for admirable resumes of recent meteorological progress. Inspiration for many pieces of research will also be found in these volumes.

SUMMARY

The object of this paper is to attract more workers to a very important field. The need for further investigation is great, and emphasis is laid upon the necessity of eliminating the frequent errors in certain experiments which are concerned with the gain or loss of heat. Examples and advice are given, particularly with reference to the proper discrimination between conflicting factors, to the treatment of humidity questions, and to the determination of the characteristics of hygroscopic surfaces.

The following list of nine problems requiring attention, are suggested as leading to researches which could be undertaken in any laboratory, and from which "results" would be almost certain. Comments and some details in regard to the general object and the possible procedure are given in each case.

(1) The variation of aqueous vapour pressure from characteristic hygroscopic substances with changing external temperature.

(2) The variation of the internal temperature with the difference in aqueous vapour pressure between that of the surface and the surrounding air, for small volumes of hygroscopic materials.

(3) The influence of the irregularity of a hygroscopic surface upon its vapour pressure.

(4) Simple methods of measuring total heat emission.

(5) The influence of turbulence and incident radiation upon instruments for measuring the rate of heat loss from bodies.

(6) The improvement of the physical apparatus employed in the calorimeter experiments on metabolism.

(7) The applications of the atmometer.

(8) The influence of atmospheric conditions upon the electrical state of a surface.

(9) The development of electrical hygrometers for precision work.

McGILL UNIVERSITY.

THE SMELTING OF TITANIFEROUS IRON ORES*

By W. M. Goodwin

Presented by Dr. R. F. Ruttan, F.R.S.C.
(Read May Meeting, 1920)

INTRODUCTION

National commercial independence rests to a great extent upon a domestic production of coal and iron. This fact, brought home so clearly to all nations since 1914, is now stirring leaders in science and industry throughout Canada. For her supplies of both these essential commodities, Central Canada is at present dependent upon her friendly neighbour, the United States. The coal supply of Ontario and Quebec must always be brought in, preferably from the sister provinces; but a domestic supply of iron and steel from native ores is not only feasible, but according to many thoughtful students of the question, expedient at the present time.

It is now commonly realized that the bulk of the iron ores of Central Canada must be subjected to some form of beneficiation to make them suitable for the present methods of smelting. A great deal of time and energy, to say nothing of money, have been spent in attempts along this line, with only a fair measure of commercial success. There is another line of endeavour, though, on which little or no work seems to have been done.

A philosophical metallurgist has pointed out[1] that metallurgical development has had a tendency to advance hindside foremost and that often it has taken years for an indirect application of an old process to a new purpose to become changed into a simpler process directly suited to that purpose. Thus for many years attempts have been made to use titaniferous iron ores in the blast furnace, mainly in mixture with non-titaniferous ores. The large tonnages of titaniferous ores available at low prices offer an inducement for their utilization that can have been offset only by real troubles that developed when their use was attempted.

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*Research carried on under the auspices of the Advisory Research Council, with whose permission this paper is published.

[1]de Alzugaray, J. Baxeres—"Direct Preparation of Ferro-Vanadium Alloys"—Min. & Eng. World, Vol. XLI, 1914.

The obvious solution of this difficulty is to *develop a method of smelting that will suit these ores.* The size of these deposits as they occur in many countries warrants a considerable effort along this line, particularly in Central Canada, where titaniferous iron ore comprises such a large fraction of our iron ore resources.

For some time past there has been in progress in the laboratories of Queen's University an attempt to find a method of smelting suited to titaniferous iron ore. This work has been based upon a study of the chemical relations of the elements involved, rather than upon the results attained in any accepted method of iron production. It is now realized by progressive metallurgists that the laws of solutions, as worked out for liquids at ordinary temperatures, apply equally well to solutions at high temperatures, such as slags.[1] That the solution which is the slag is the predominant factor in the smelting of iron, is well put thus. "The production of a high-grade slag means the production of a high-grade pig-iron. Scientifically considered, the blast furnace is primarily a machine for manufacturing slag, the pig-iron being a necessary by-product."[2] The gangue materials of the average titaniferous iron ore consist essentially of titania, silica and alumina, with magensia next in importance and lime in comparatively insignificant amount.[3] If a satisfactory slag can be made consisting essentially of the same ingredients in like proportions, then ideal smelting conditions for this ore will have been provided.

An examination of Mendelejeff's periodic arrangement of the elements shows that calcium and magnesium are on the basic side of the table, and that aluminium is inclined that way. Silicon and titanium, in the central group, may swing either way. But experience has shown that, while aluminium and titanium are truly amphoteric, silicon has a decidedly acidic tendency. Thus, in iron blast-furnace practice, silica and lime are made the major constituents of the slag, and flux one another satisfactorily, with the help of smaller amounts of alumina, magnesia, ferric oxide and so on. Now, to get the ideal slag for the ores under

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[1]Johnson, J. E., Jr.—"Principles, Operation and Products of the Blast Furnace." 1918, Page 21.

Feild & Royster—"Slag Viscosity Tables for Blast Furnace Work." U. S. Bureau of Mines, Tech. paper 187, 1918, page 5.

Morey, G. W.—"Solubility and Fusion Relations at High Temperatures and Pressures." Jour. Engineers' Club of Philadelphia, Nov., 1918.

[2]Feild & Royster, as above, page 14.

[3]Pope, F. J.—"Investigation of Magnetic Iron Ores from Eastern Ontario." Trans. A.I.M.E., 1899.

Singewald, J. T., Jr.—"The Titaniferous Iron ores in the United States." U. S. Bureau of Mines, Bull. 64—1913.

consideration, it ought theoretically to be possible to induce titania to act, with lime and magnesia, as a base. The obvious means of effecting this is to provide sufficient silica to flux the titania, lime and magnesia, the alumina being considered, as usual, as either acidic or basic, and an adjunct in providing a fluid slag. This is the line of reasoning that has led the writer and his associates to follow the line of investigation outlined in the following pages.

Acknowledgment must here be made of the active and continued co-operation in this research of Dr. W. L. Goodwin, Prof. A. F. G. Cadenhead and Dr. C. W. Drury, all of Queen's University. Without their co-operation the work could not have been undertaken.

LITERATURE ON THE SUBJECT

Though it is a matter of such general importance, comparatively little has been published concerning the smelting of titaniferous iron ores. A good bibliography is given by Dr. Stansfield[1] and numerous references by Bradley Stoughton[2] and J. T. Singewald, Jr.[3]. The results of previous investigations are summarized here in chronological order.

From time immemorial titaniferous iron ores have been used in the ancient forges of Norway and Sweden to produce iron and steel.[4] Even when the blast furnace came into use, they were successfully treated in the new apparatus, and a variant of the accepted smelting practice of the time (1847) is described by Dr. Forbes,[5] who used quartz in addition to limestone to flux the ore. From 1840 to 1846 a furnace was operated on the Adirondack River, using titaniferous ore from the Sanford Hill deposits, with limestone and labradorite as flux.[6] This furnace was closed down for financial reasons only. Another such attempt that was a metallurgical success but a business failure was made at Norton in England, where Dr. Forbes in 1868 successfully smelted Norwegian ilmenite, using limestone and old bricks as flux and producing a fluid slag very near the mineral sphene in composition.[7]

[1]Stansfield & Wissler—"The Smelting of Titaniferous Ores of Iron." Trans. Royal Soc. Canada, Vol. 10, 1916.

[2]Stoughton, Bradley—"The Smelting of Titaniferous Iron Ores." Trans. Can. Min. Inst., 1915.

[3]Singewald, J. T., Jr., as above.

[4]Sjogren, H.—"Geological Relations of the Scandinavian Iron Ores." Trans. A.I.M.E., XXXVIII, 1907, page 813.

[5]Forbes, David—"On the Composition and Metallurgy of some Norwegian Titaniferous Iron Ores" Chemical News, Dec 11, 1868.

[6]Rossi, A. J.—"Titaniferous Ores in the Blast Furnace." Trans. A.I.M.E., Vol. XXI, 1892-3.

[7]Bowron, W. M.—"The Practical Metallurgy of Titaniferous Ores." Trans. A.I.M.E., Vol. XI, 1882-3.

The first attempt to solve the problem of smelting these refractory ores along modern scientific lines was that of Dr. Rossi, [1] in 1892, With the idea of producing titanates as well as silicates in the slag, that is to say, considering titania to act as an acidic constituent, he made a long series of pot tests to compare the relative fluidity of various slags made of weighed quantities of pure slag-making materials. These were followed by a run in a small experimental blast furnace, where good iron and fluid slags were made in spite of difficulties in the operation of such a small furnace. These results stimulated further work and in 1906 Cox and Lennox[2] made extensive cone tests with slag-forming mixtures that corroborated and extended Rossi's information. Pyrometers for measuring high temperatures, now available for the first time, were used to check the temperatures at which the cones softened.

A most refined method of determining the characteristics of rock- and slag-forming materials, is that developed by the Geophysical Laboratory of the Carnegie Institute in Washington.[3] Fluid melts of various compositions are quenched from measured temperatures, and the condition of the molten material, stabilized or "frozen" by this means, is examined with the microscope. No mixtures containing titania have yet been examined at the Geophysical laboratory; but in Petrograd, Smolensky has investigated by this means mixtures of the titanates and silicates of calcium, manganese and barium.[4] An application of the method to the essential constituents of titania-bearing slags would no doubt yield much information of scientific and practical importance.

The most extensive and conclusive test to date of the use of titaniferous iron ore is that conducted by Bachman at Port Henry, New York, in 1914.[5] It was found that this ore, mixed with ordinary magnetite up to five sixteenths of the total, did not interfere in any way with the normal working of the furnace, the flux being, as usual limestone. Another extensive large-scale test using titaniferous magnetic sand was made in New Zealand in 1918[6] using limestone and a silicious volcanic rock as flux.

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[1]Rossi, A. J., as above.

[2]Cox, C. N. Jr., and Lennox, L. C.—"Tests of Titaniferous Slags." Electrochem. and Met. Ind., Vol. IV, 1906.

[3]Rankin, G. A—"Portland Cement." Jour. Franklin Inst., June, 1916.

Bowen, N. L.—"The Binary System $Na_2Al_2Si_2O_8$—$CaAl_2Si_2O_8$." Amer Jour. Science, Vol. XXXIII, June, 1912.

[4]Smolensky, S.—"Schmelzversuche mit Bisilikaten und Titanaten." Zeitschr. anorg. Chem., Vol. 73, 1912.

[5]Cone, E. F.—"Titanium Ores in the Blast Furnace." Iron Age, October 22, 1914.

[6]Aubel, V. W.—"Titaniferous Iron Sands of New Zealand." Bull. A.I.M.E., Sept., 1919.

The most complete information available about the softening points of mixtures containing titania is given by Dr. Stansfield.[1] His investigation also included two furnace runs from which he concluded that silica as well as limestone should be used to flux the ore.

Accepting the idea that the slag is the proper point of attack in attempting to smelt an iron ore, a comparison of the slags produced in the furnace runs quoted above will be instructive.

TITANIA SLAGS

	I	II	III(a)	III(b)	III(c)	IV	V	VI
FeO	3.46%	1.86%	13.50%	12.50%	6.30%	.....	*2.76%	1.15%
SiO_2	26.72	27.83	41.27	21.71	22.16	28	36.75	32.40
CaO	25.81	24.36	8.88	18.38	9.51	.....	22.65	35.80
MgO	5.99	0.60	5.42	9.05	5.34	.....	2.67	6.36
Al_2O_3	11.86	9.18	16.50	13.76	15.58	**14	10.14	15.17
TiO_2	25.11	36.18	14.96	24.73	40.81	10	25.16	7.09
	98.95%	100.01%	100.53%	100.13%	99.70%		100.13%	97.97%

(*Fe O reduced to normal.) (**+Fe O).

I McIntyre furnace, Adirondack River, 1840-56.

11. Norton, England—1868.

III. Rossi, Perth Amboy, N. J.—1892.

(*a*) First slag from run.

(*b*) Slag, first eight hours of run.

(*c*) Slag toward end of run.

IV. Bachman's run, Port Henry, N.Y.—1914.

V. Stansfield's run, Montreal, 1916.

VI. Run on Taranaki sands, New Plymouth, N.Z., 1918.

Of these slags, I, II, III (b), and V are much alike, in that the proportions of silica, lime plus magnesia, and titania in each are nearly equal, and so the composition of the slags is approximately that of the mineral sphene. This result was arrived at in I by empirical means; in II deliberately, in imitation of the easily fusible mineral; in III (b) and V by calculation, following pot tests and cone tests. IV and VI follow regular iron blast-furnace practice with titania as a minor constituent. III (c) shows very high titania, at the expense partly of silica and partly of lime. In each of these cases the operator or investigator has conceded, by accident or by design, that a fairly high percentage of silica is necessary in order to get a fluid slag. The slag III (a) only, which Rossi obtained accidentally by fluxing the lining of his furnace, brings out the point that

[1]Stansfield, A., and Wissler, W. A.—"The Smelting of Titaniferous Ores of Iron." Trans. Royal Soc. Canada, Vol. X, 1916.

has proved of value in the present experiments, namely that there are fluid slags consisting essentially of silica, titania and alumina.

METHODS

A brief account of the means and methods used in attacking this problem follows. With an object in view other than the simple production of pig-iron, a careful study was made of the chemical relations of the various materials composing the ore, as set down above. Laboratory tests were made, and these led to the undertaking, under private auspices, of smelting tests on a small commercial scale. The slags so produced seemed worthy of detailed study, and the interest and financial aid of the Advisory Research Council were obtained for this purpose. The study is still far from complete but the results to date are believed to be of sufficient public interest to warrant the presenting of this paper.

FURNACE

Since the softening points of synthetic mixtures representing slags has been thoroughly investigated[1], and since the relation between such determinations and the fluidity of actual slags is an unknown factor,[2] it was decided to approximate as closely as possbile to large-scale smelting conditions from the beginning. The electric furnace was chosen as the best means of smelting for several reasons. First and foremost is the fact that with even a small electric furnace, high temperatures can be got with comparative ease. Then it is to our advantage in Central Canada to have, if possible, smelting methods independent of imported coal. Another cogent reason for adopting the electrical method is that it is a "coming" method. As has been stated aptly by more than one authority (possibly enthusiasts), if our knowledge of electric furnace operation approached in completeness our knowledge of the blast furnace, the latter would soon be an obsolete appliance. The raw materials used were prepared in no especial way, being such as would be used in large-scale practice.

The furnace, built for this purpose, is an iron box, balanced on trunnions, lined and roofed with silica brick round a crucible nine inches in diameter. The pouring spout serves also as charging door. Single-phase electric current is supplied at any desired voltage through a graphite electrode built into the bottom of the furnace, and an adjustable electrode of two inches in diameter through the roof. The power used

[1]Stansfield & Wissler; Rossi; and Cox and Lennox, as above.

[2]Feild, A. L., —"A Method for Measuring the Viscosity of Blast-Furnace Slag at High Temperatures." U. S. Bureau of Mines, Tech. Paper 157, 1916.

Cox and Lennox, as above.

Johnson, J. E., as above, p. 202.

in these experimental runs has been from 30 to 60 kilowatts, at 60 volts. The furnace is heated thoroughly before charging ore by means of passing the current through a resistant bed of charcoal between the electrodes. This preliminary heating takes several hours, even when the furnace is dry and warm from previous operation. When the furnace walls are sufficiently hot, ore, charcoal and flux, mixed in appropriate proportions, are fed between the electrodes, slowly enough to prevent any undue chilling of the crucible. Until a fluid bath of resistant slag is formed, it is usually difficult to regulate the current passing through the furnace. When the charge has been completely smelted (usually a matter of three or four hours with 100 lbs. of ore), the metal and slag are poured into pots or molds by tilting the furnace.

PRYOMETER

The temperature of the bath of metal and slag has been determined by sighting on the lining of the furnace immediately after pouring, with an optical pyrometer. As the volume of slag and metal is small, it chills on leaving the furnace, and no reliable readings of temperature can then be obtained. The instrument used is the F. and F. optical pyrometer of the Scientific Materials Company. It is a modification of the Wanner pyrometer, which makes use of the principle that "when the temperature increases, the wave length of every mono-chromatic radiation diminishes in such a way that the product of the temperature and the wave length is constant."[1] By means of an arrangement of lenses and Nicol prisms, red light from a six-volt incandescent lamp is viewed through an eye-piece side by side with the same red light from the hot body whose temperature is to be measured. A Nicol analyser in the eye-piece is rotated to make the two reds alike, and this angular movement, indicated on a graduated circle, is marked to correspond with degrees of temperature. The small electric lamp in the instrument is calibrated occasionally against a flame of standard amyl acetate, using a resistance to vary the current from the storage battery. This method of measuring high temperatures is said to be accurate if reasonable precautions are observed.

ANALYSIS

As no existing method of complete analysis was found suitable for ores and slags high in titanium, the investigation had to be preceded by the working out of such a method. As the result of several months of analytical research on the part of W. L. Goodwin and A. F. G. Cadenhead, existing schemes of analysis were modified and adapted to this purpose

[1]Burgess—"Measurement of High Temperatures." 1912, p. 315.

in a satisfactory way. Titania is what causes trouble throughout, unless special precautions are taken.

The practical detail of analysis has been taken mainly from publications of the United States Steel Corporation,[1] the items being modified, re-arranged and altered as found necessary.

The analysis of the pig-iron produced for carbon, silicon and titanium presents no difficulties, and the procedure as laid down by the United States Steel Corporation,[1] has been followed.

RESULTS

RAW MATERIALS

For the purpose of this investigation, a two ton lot of titano-magnetite from an Eastern Ontario deposit was crushed, sampled and analyzed, with the following results.

ANALYSIS OF IRON ORE USED

Fe_3O_4 (assumed)	66.59%
SiO_2	7.40
CaO	3.42
MgO	4.73
Al_2O_3	5.81
TiO_2	11.80
MnO	0.36
	100.11%

A half-ton lot of common building sand was sampled and analysed for use as flux.

ANALYSIS OF FLUX (sand)

SiO_2	69.0 %
CaO	10.30
MgO	2.64
Al_2O_3	8.29
	90.23%

FeO, K_2O, Na_2O and CO_2 not determined.

[1] U. S. Steel Corp.—"Methods for the Commercial Sampling and Analysis of—"Pig Iron," 1912; "Iron Ores," 1912; "Plain Steels," 1914; "Alloy Steels," 1915; "Slags," (not yet published).

Hardwood charcoal, as prepared by the Standard Chemical, Iron and Lumber Co. was used as reducing agent. It analysis was assumed to be that of the average hardwood charcoal, with 1 per cent. or less of ash.[1]

To provide a basis for charge calculations, some slags that had proved satisfactory in former tests were analysed, with results as follows. These tests had been run in an empirical way, without a complete analysis of the materials used.

SLAGS FROM FORMER TESTS

	B. 31	B. 33
FeO	2.30%	3.96%
SiO_2	42.25	36.61
CaO	6.85	7.55
MgO	9.19	10.29
Al_2O_3	15.23	16.61
TiO_2	20.80	22.55
MnO	0.80	0.70
C	0.60	0.20
	98.02%	98.47%

The furnace charge was simply calculated as below. The amount of ash in the charcoal was taken as too small to be considered under the circumstances. It will be noted by reference to the analyses of slags produced from this charge as determined later that they approximate fairly closely to the slags as calculated.

	100 lbs. Ore Contains	In Pig Iron	Remainder in Slag	20 lbs. Sand	Total in in Slag	Composition of Slag
Fe	48.27 lbs.	47 lbs.	1.6 lbs. (FeO)	.....	1.6 lbs.	3.4%
SiO_2	7.40	5.3	2.1	13.8	15.9	33.5
CaO	3.42	.....	3.4	2.1	5.5	11.6
MgO	4.73	.....	4.7	0.5	5.2	11.0
Al_2O_3	5.81	.....	5.8	1.6	7.4	15.6
TiO_2	11.80	.....	11.8	.....	11.8	24.9
					47.4 lbs.	100.0%

[1]Johnson, J. E., as above, page 50.

PRODUCTS OF RUNS

It was found that by observing reasonable precautions the above charge smelted satisfactorily in the electric furnace used, producing ordinary grades of pig-iron and fluid slags. Four runs have been made and the products analysed. The slag and pig-iron from the first run are number G1 and G2 respectively; G3 (slag) and G4 (iron) from the second run and so on. In the fourth run (samples G7 and G8) the charge was fed too rapidly into the furnace with the consequence that the crucible was chilled and only an imperfect separation of iron and slag took place, part of the reduced iron, including a small amount of slag, remaining "frozen" on the bottom of the furnace after pouring, and a small percentage of "sponge metal" remaining in the slag, as indicated in analysis G7, where a normal amount of the ferrous oxide determined is recorded as such and the remainder of the iron assumed to be in the metallic state.

ANALYSIS OF SLAG FROM RUNS

	G 1	G 3	G 5	G 7	(a)	(b)	(c)
FeO	2.9%	4.0%	3.7%	3.1%	.....	.....	3.46%
SiO_2	44.5	35.3	35.6	36.2	33.%	35. %	26.72
CaO	7.0	6.1	8.1	8.4	41.	40.	25.81
MgO	13.2	12.1	10.8	10.6	11.	5.5	5.99
Al_2O_3	13.8	17.5	15.9	16.9	12.	13.	11.86
TiO_2	17.4	26.1	25.6	21.7	.....	.....	25.11
MnO	0.3	0.3	0.6	0.4	.....	.....	.....
	99.1%	101.4%	100.3%	97.3%			
Fe (asumed)				5.0%			
				102.3%			

(*a*) Average iron blast-furnace slag, after Bradley Stoudhton.[1]
(*b*) Average iron blast furnace slag, after Feild & Royster.[2]
(*c*) Slag from McIntyre furnace, Adirondacks.[3]

In the above table the composition of regular blast-furnace slag and of the slag produced in a typical and successful commercial operation with a titaniferous ore, are given for comparison. It will be noted that

[1]Stoughton, Bradley.—"Metallurgy of Iron and Steel," 1908, p. 37.
[2]Feild & Royster.—"Slag Viscosity Tables for Blast-furnace Work."—as above, p. 17.
[3]Rossi, A. J., as above.

the main difference between the average blast-furnace slag and the new slag is that in the latter titania is substituted for the major part of the lime of the former. The slag from the McIntyre furnace has taken this substitution only part way, and has a considerably lower silica content.

Slag G1 has more silica than provided for in the charge. In this, the first run with a new lining, the brick was corroded to provide the extra silica. In spite of the high percentage of silica, the slag was normally fluid.

These slags are invariably black and heavy. The weight is accounted for by the high content of titania, the specific gravity of rutile (TiO_2) being 4.2. An examination under the microscope shows the black colour to be due to a multitude of minute particles of iron oxide, which make it opaque as well. In one of the slags, well formed crystals were produced, but their opacity made an optical examination impracticable.

The reduction of the lime to the position of a minor constituent is the feature that makes this slag radically different from those used heretofore. Dr. Rossi in his experimental run had similarly low percentages of lime, but reduced the silica correspondingly, and considered titania to be the equivalent of so much silica in the chemical reactions involved. In the present case, the titania acts as so much lime.

It is probable, though not yet proved in this investigation, that the comparatively high percentage of magnesia tends to make the slags more fluid. If so, this will conform to the unanimous conclusion of those who have already investigated this point in connection with titania-bearing slags. The percentage of alumina present, too, is near the amount commonly considered beneficial in a slag.

ANALYSIS OF PIG-IRON FROM RUNS

					Standard Pig-Iron*			
	G 2	G 4	G 6	G 8	Foundry No. 1	Forge	Basic O. H.	Acid Bessemer
C	2.53	2.53	2.56	3.04	3 to 4%	3 to 4%	3.5 to 4%	3.5 to 4%
Si	4.99	3.91	1.28	1.90	2.75	0.75 to 1.75	under 1.00 %	0.80 to 2.00
Ti	0.02	0.02	0.01	0.01	.....	.....	.....	.....

*Stoughton, Bradley.—"Metallurgy of Iron and Steel," page 104.

The proportions of carbon and silicon in the pig-iron produced in these tests does not conform strictly to any of the recognised standards. From a consideration of the physical properties as given further on, it

seems that this iron might be suitable for some foundry purposes, in spite of discrepancies in the composition. The greatest use, though, would seem to be for conversion into steel. Titaniferous ores are commonly very low in phosphorus and sulphur, and this iron might be useful in the acid Bessemer process, and so help to restore the cheapest known method of steel production.

The amount of titanium in the iron is so small that it seems probable this metal is accidentally included with particles of slag rather than alloyed with the iron. All the determinations to date of titanium in iron and slag uphold the theory advanced in the introductory part of this paper, namely that by producing the proper conditions in the molten materials of the furnace this amphoteric element can be made to go completely into the slag solution if desired. The high percentage of silica and low proportion of lime is the necessary condition in this case.

The physical properties of the pig-iron have been examined in only an incidental way, but the results, considered in connection with the composition, are rather interesting.

PHYSICAL PROPERTIES OF PIG-IRON FROM RUNS

	Drills	Fracture	Toughness
G 2	Freely	Fine-grained grey	Fairly tought, rather soft and malleable.
G 4	Freely, but is hard, and drill must be ground frequently	Fine-grained grey	Very tough, somewhat malleable.
G 6	Fairly freely	Fine-grained grey	Very tough, slightly malleable.
G 8	With difficulty	Fine-grained grey	Very tough, slightly malleable (less than G 6)

An ordinary carbon steel drill was used. To judge of the malleability, it was noted to what extent a sharp edge would stand flattening with a hammer. The comparatively high malleability and toughness in combination with such hardness are not usual with ordinary irons.

TEMPERATURES

The temperatures here tabulated, each of them the average of a number of readings, indicate the fact that the closest approximation that can be got to the temperature of the fluid materials in the furnace, is by sighting on the furnace lining after pouring the charge, and after the fumes in the furnace have cleared away. With a large furnace, there is no doubt that more accurate determinations can be made in other ways.

APPROXIMATE TEMPERATURES OF THE RUNS

Run	Temp. on Stream of Slag.	Temp. on Furnace Lining	Nature of Slag
G 1 and 2	2380°F = 1304°C.	2480°F = 1360°C.	Fluid
G 3 and 4	2200°F = 1204°C.	2400°F = 1315°C.	Fluid
G 5 and 6	*2600°F = 1426°C.	2420°F = 1326°C.	Very fluid
G 7 and 8	2530°F = 1388°C.	2480°F = 1360°C.	Slag fluid. Most of iron "frozen" on bottom.

*Reading taken on bubbling slag round electrode before pouring.

These temperatures from 1315°C. to 1360°C. are well below the temperature at which the average iron blast-furnace slag runs from the furnace, namely 1450°C.[1]

It has been realised by some investigators who have gone fully into the subject, that temperatures determined in the ways noted above are, at the best, approximations[2]. The ordinary determinations of slag as "sticky," "free-running," "fluid," and so on, are likewise rather vague. Hence any conclusions on the question of the temperature-viscosity relations of slags based upon such data is bound to be inconclusive, and of a rather un-scientific character. The United States Bureau of Mines has in the course of an investigation of blast-furnace slags gone fully into the question of their temperature-viscosity relations. The work of Feild & Royster on this problem[3] is impressive in its completeness, and seems to be founded on sound scientific principles. The procuring of similar information with regard to this new titania slag might afford a sound basis on which to make it useful in smelting on an industrial scale, and might also save the years of time that would in all probability be consumed in gaining the necessary information in an empirical way.

To determine temperature-viscosity relations with the precision necessary to make the results useful, a machine was devised in which the drag or torsion was measured between an inner stationary spindle and an outer rotating crucible filled with molten slag, the latter being kept in the fluid condition by an electric furnace that enclosed the apparatus. The viscosities of actual blast-furnace slags of varying compositions

[1]Johnson, J. E., as above, p. 32.
Feild & Royster.—"Slag Viscosity Tables for Blast Furnace Work," p. 23.

[2]Johnson, J. E., Jr., as above, p. 50 and (quoting A. L. Feild), p. 228.

[3]Feild, A. L., and Royster, P. H. Tech Papers Nos. 157, 187, and 189, U. S. Bureau of Mines.

were thus determined, each through a considerable range of temperature, and the results embodied in curves and tables. This method of determining in an accurate way the fluidity of slags and so of helping to solve the problem of chemical control in a furnace, seems to be capable of wide application, and worthy of serious consideration in a case such as the one being discussed.

SELF-FLUXING ORE

On comparing the analyses of the titania slags as determined above with the recorded analyses of some Canadian titaniferous ore deposits it was noticed that the slag-forming materials of the latter approximated fairly closely to the former. A further study of the matter revealed the fact that in a number of cases at least, Nature had provided, ready mixed with the ore as ferro-magnesian silicates, the fluxing material that had been added in the form of sand in the smelting experiments. This high proportion of silica has always caused this class of ore to be considered as of little value, where it had to be fluxed with the addition of lime in regular blast-furnace practice. In this method of smelting, on the other hand, the silica in the ore is an asset.

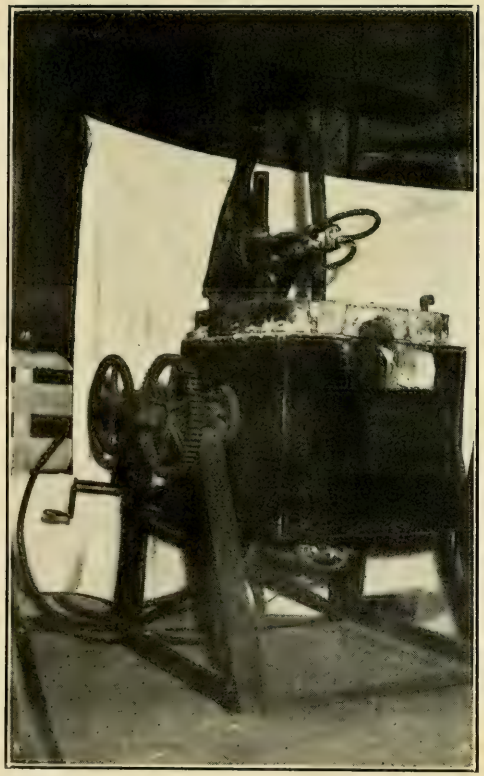
ANALYSES INDICATING SELF-FLUXING ORE

	I	II	III	IV	V	VI	VII
Fe	49.8%	44.5%	48.5%	38.8%	40.5%	59.6%	
SiO_2	27	31	31	33	37	34	35
CaO	8	13	14	7	9	8	6
MgO	11	6	13	8	18	12	12
Al_2O_3	16	13	15	*21	8	12	18
TiO_2	37	38	25	31	28	34	26

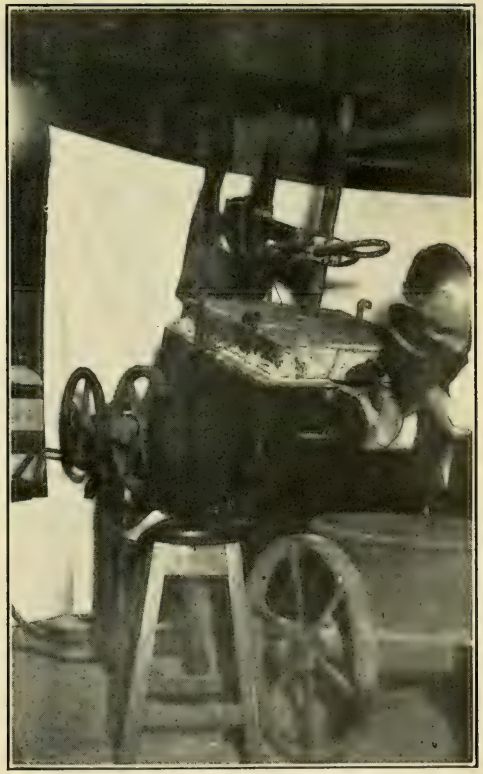
*By difference.

I —Chaffey Mine—F. J. Pope—as above.
II —Pine Lake Deposit—F. J. Pope.
III —Millbridge, Hastings County—F. J. Pope.
IV —Seven Islands, Gulf of St. Lawrence—E. Dulieux, Mining Op. Quebec, 1911, p. 124.
V —An Ontario deposit.
VI —A Newfoundland deposit.
VII—Slag G 3 (for comparison).

The above table shows in column VII, a typical analysis of the titania slag (G 3) and in the other columns, the slag-making constituents of



Furnace used in experiments



Use of pyrometer

the ore in the proportions in which they would appear in the slag, if self-fluxing. Ores I, II and III were sampled by Mr. Pope only across those parts of the deposits that did not include any large proportion of rock-forming crystals and it is probable that by including some of the marginal phase of the deposits, the proportions of the slag-forming ingredients can be adjusted to suit exactly the requirements of the slag.

If these determinations of self-fluxing ores should prove on more extended trial, to be correct, there will be a new field opened for the prospecting and development of titaniferous iron ore. The marginal parts of these ore deposits are known to merge gradually into rock in many cases, and in some cases on record these marginal rocky parts greatly exceed in tonnage the parts composed of pure titano-magnetite or ilmenite. Where this self-fluxing ore reaches 40 per cent. in iron, the furnace burden will be equal to or higher than the average North American blast-furnace burden in iron content. It seems probable that some of these deposits will provide an ore of self-fluxing composition that will run considerably over 40 per cent. in iron.

CONCLUSIONS

The data and speculations set forth above have led to the following conclusions:

1. There has been demonstrated the use, in the electric furnace, of a slag consisting essentially of titania, silica and alumina, whereby titaniferous iron ores can be satisfactorily reduced to pig-iron.

2. The smelting temperatures are not above those in use with the ordinary iron blast-furnace.

3. It is not yet proved that this process is applicable to the blast furnace, but the evidence up to the present shows that this will be the case.

4. The experiments to date show that there is a considerable range of composition through which this slag can be usefully employed; but the limits have not yet been determined.

5. The use of this slag seems particularly adaptable to titaniferous ores that are high in silica, and consequently self-fluxing. There are large deposits of this class of ore with a suitably high iron content, that have up to the present been considered as of no immediate or prospective value.

6. It is recommended that the temperature-viscosity relations of this slag be studied by means of the method devised by the United States Bureau of Mines, as an aid in effecting chemical control of the smelting operation.

Kingston, May 15th, 1920. W. M. GOODWIN.

ALGEBRAIC THEORY OF KAPTEYN SERIES

By James Harkness, M.A., F.R.S.C.

(Read May Meeting, 1920)

In 1893 Kapteyn devised a new type of expansion in Bessel Functions, and later it was shown by Nielsen that the Bessel functions employed could be of the most general character, namely those defined by

$$J_\nu(x) = \sum_{n=0}^{\infty} \frac{(-1)^n \left(\frac{x}{2}\right)^{\nu+2n}}{n!\ \Gamma(\nu+n+1)},$$

where ν is an arbitrary parameter, free to take complex as well as real values.

Employing Nielsen's notation one result arrived at by Kapteyn for the case $\nu=0$, and generalized by Nielsen so as to cover all finite values of ν other than negative integers, is that the power series $f(x) = \sum_0^\infty a_n \left(\frac{x}{2}\right)^n$ can be expanded in the form

$$\left(\frac{2}{x}\right)^\nu \sum_0^\infty \frac{b_n^\nu}{(\nu+n)^{\nu+1}} J_{\nu+n}\left((\nu+n)x\right),$$

the coefficients b being expressible in terms of the a's by linear relations of the form

$$b_n^\nu = \sum_{p=0}^{\leqq n/2} \frac{(\nu+n-2p)^2\ \Gamma(\nu+n-p)}{p!\ (\nu+n)^{n-2p}} a_{n-2p}.$$

The J-series that arises in this way is called a Kapteyn series of the first kind and its convergence is unconditional within a certain neighbourhood of $x=0$.

The theorem presupposes the possibility of the expansion

$$\left(\frac{x}{2}\right)^\nu = \sum_0^\infty a_{2n}^\nu J_{\nu+2n}\left((\nu+2n)x\right). \qquad (1)$$

(See Nielsen's Handbuch der Theorie der Cylinderfunktionen, Chap. 22, p. 300.)

By expanding the J's on the right hand side of (1) and equating the coefficients of the powers of x we are led to a series of equations (in which a^{ν}_{2n} is replaced by a_{2n})

$$\left.\begin{aligned} 1 &= \frac{\nu^{\nu}}{\Gamma(\nu+1)}\, a_o\,, \\ 0 &= \frac{\nu^{\nu+2}}{\Gamma(\nu+2)}\, a_o - \frac{(\nu+2)^{\nu+2}}{\Gamma(\nu+3)}\, a_2\,, \\ 0 &= \frac{\nu^{\nu+4}}{2!\,\Gamma(\nu+3)}\, a_o - \frac{(\nu+2)^{\nu+4}}{\Gamma(\nu+4)}\, a_2 + \frac{(\nu+4)^{\nu+4}}{\Gamma(\nu+5)}\, a_4 \\ &\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots \end{aligned}\right\} \qquad (2)$$

which are simplified by replacing $\frac{\nu^{\nu}}{\Gamma(\nu+1)}\, a_o$ by β_o, $\frac{(\nu+2)^{\nu+2}}{\Gamma(\nu+3)}\, a_2$ by β_2, $\frac{(\nu+4)^{\nu+4}}{\Gamma(\nu+5)}\, a_4$ by β_4, etc. They thus take the form

$$\left.\begin{aligned} 1 &= \beta_o \\ 0 &= \frac{\nu^2}{\nu+1}\,\beta_0 - \beta_2 \\ 0 &= \frac{\nu^4}{2!\,\nu+1.\nu+2}\,\beta_0 - \frac{(\nu+2)^2}{1!\,\nu+3}\,\beta_2 + \beta_4 \\ 0 &= \frac{\nu^6}{3!\,\nu+1.\nu+2.\nu+3}\,\beta_0 - \frac{(\nu+2)^4}{2!\,\nu+3.\nu+4}\,\beta_2 + \frac{(\nu+4)^2}{1!\,\nu+5}\,\beta_4 - \beta_6 \\ &\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots \end{aligned}\right\} \qquad (3)$$

The first few values of the set of β's are readily seen to be

$$\beta_0 = 1,\ \beta_2 = \frac{\nu^2}{1!}\,\frac{(\nu+2)^0}{\nu+1},\ \beta_4 = \frac{\nu^2}{2!}\,\frac{(\nu+4)^2}{\nu+2.\nu+3},\ \beta_6 = \frac{\nu^2}{3!}\,\frac{(\nu+6)^4}{\nu+3.\nu+4.\nu+5}.$$

They point to the general formula

$$\beta_{2n} = \frac{\nu^2}{n!}\,\frac{(\nu+2n)^{2n-2}}{\nu+n.\nu+n+1\ldots.\nu+2n-1} \qquad (4)$$

This formula can be established by mathematical induction (see Neilsen, p. 301). We propose to study the equations (3) from another point of view which will give us an insight into the algebraic nature of the foundations on which the structure of Kapteyn series rests.

Replace β_{2s} by $\frac{\nu^2}{s!}(\nu+2s)^{2s-2}\gamma_{2s}$, $s=1, 2, 3, \ldots\ldots$

and β_0 by 1. The first four γ-equations are:

$$\left.\begin{aligned}
0 &= \frac{\nu^0}{\nu+1} - \frac{(\nu+2)^0}{1!}\gamma_2 , \\
0 &= \frac{\nu^2}{2!\,\nu+1.\nu+2} - \frac{(\nu+2)^2}{\nu+3}\gamma_2 + \frac{(\nu+4)^2}{2!}\gamma_4 \\
0 &= \frac{\nu^4}{3!\,\nu+1.\nu+2.\nu+3} - \frac{(\nu+2)^4}{2!\,1!\,\nu+3.\nu+4}\gamma_2 + \frac{(\nu+4)^4}{1!\,2!\,\nu+5}\gamma_4 - \frac{(\nu+6)^4}{3!}\gamma_6 \\
0 &= \frac{\nu^6}{4!\,\nu+1.\nu+2.\nu+3.\nu+4} - \frac{(\nu+2)^6}{3!\,1!\,\nu+3.\nu+4.\nu+5}\gamma_2 + \\
&\qquad \frac{(\nu+4)^6}{2!\,2!\,\nu+5.\nu+6}\gamma_4 - \frac{(\nu+6)^6}{1!\,3!\,\nu+7}\gamma_6 + \frac{(\nu+8)^6}{4!}\gamma_8
\end{aligned}\right\} \quad (5)$$

The solutions of these equations are

$$\gamma_2 = \frac{1}{\nu+1} , \quad \gamma_4 = \frac{1}{\nu+2.\nu+3} , \quad \gamma_6 = \frac{1}{\nu+3.\nu+4.\nu+5} , \quad \gamma_8 = \frac{1}{\nu+4.\nu+5.\nu+6.\nu+7}$$

If these values are inserted in (5) the resulting equations can be written in the form

$$\begin{array}{rl|rl}
\nu+3 & \nu^2 & \nu+4.\nu+5 & \nu^4 \\
-2(\nu+2) & (\nu+2)^2 & -3.\nu+2.\nu+5 & (\nu+2)^4 \\
 & & +3.\nu+1.\nu+4 & (\nu+4)^4 \\
+(\nu+1) & (\nu+4)^2 = 0 & -\ \nu+1.\nu+2 & (\nu+6)^4 = 0
\end{array} \quad (6)$$

$$\begin{array}{rl}
\nu+5.\nu+6.\nu+7 & \nu^6 \\
-4.\nu+2.\nu+6.\nu+7 & (\nu+2)^6 \\
+6.\nu+1.\nu+4.\nu+7 & (\nu+4)^6 \\
-4.\nu+1.\nu+2.\nu+6 & (\nu+6)^6 \\
+\ \nu+1.\nu+2.\nu+3 & (\nu+8)^6 = 0
\end{array}$$

It is to be remarked that the sum to the left of a vertical line is in each case zero. These sums can be transformed into

$$\left.\begin{aligned}
&\frac{\nu}{\nu.\nu+1.\nu+2} - 2\frac{\nu+2}{\nu+1.\nu+2.\nu+3} + \frac{\nu+4}{\nu+2.\nu+3.\nu+4} = 0 \\
&\frac{\nu}{\nu.\nu+1.\nu+2.\nu+3} - 3\frac{\nu+2}{\nu+1.\nu+2.\nu+3.\nu+4} + 3\frac{\nu+4}{\nu+2.\nu+3.\nu+4.\nu+5} - \\
&\qquad \frac{\nu+6}{\nu+3.\nu+4.\nu+5.\nu+6} = 0 \\
&\frac{\nu}{\nu.\nu+1.\nu+2.\nu+3.\nu+4} - 4\frac{\nu+2}{\nu+1.\nu+2.\nu+3.\nu+4.\nu+5} + \\
&\quad 6\frac{\nu+4}{\nu+2\ldots\nu+6} - 4\frac{\nu+6}{\nu+3\ \ldots\ \nu+7} + \frac{\nu+8}{\nu+4\ \ldots\ \nu+8} = 0
\end{aligned}\right\} \quad (7)$$

The numerators constitute the series ν, $\nu+2$, $\nu+4$, $\nu+6$, ..., the numerical coefficients are the binomial coefficients with signs alternately plus and minus, and the denominators follow a law that is evident on inspection.

The complete system (6) can be written

$$\left.\begin{aligned}
&\frac{\nu^3}{\nu.\nu+1.\nu+2} - 2\,\frac{(\nu+2)^3}{\nu+1.\nu+2.\nu+3} + \frac{(\nu+4)^3}{\nu+2.\nu+3.\nu+4} = 0\\
&\frac{\nu^5}{\nu.\nu+1.\nu+2.\nu+3} - 3\,\frac{(\nu+2)^5}{\nu+1.\nu+2.\nu+3.\nu+4} + 3\,\frac{(\nu+4)^5}{\nu+2.\nu+3.\nu+4.\nu+5} -\\
&\qquad\qquad \frac{(\nu+6)^5}{\nu+3.\nu+4.\nu+5.\nu+6} = 0\\
&\frac{\nu^7}{\nu.\nu+1.\nu+2.\nu+3.\nu+4} - 4\,\frac{(\nu+2)^7}{\nu+1.\nu+2\ldots\nu+5} + 6\,\frac{(\nu+4)^7}{\nu+2\ldots\nu+6} -\\
&\qquad\qquad 4\frac{(\nu+6)^7}{\nu+3\ldots\nu+7} + \frac{(\nu+8)^7}{\nu+4\ldots\nu+8} = 0
\end{aligned}\right\} \quad (8)$$

The resemblance in structure between (7) and (8) is at once apparent. The denominators are the same in corresponding terms; there is the same law as to the numerical coefficients and the only novelty consists in replacing the first powers of ν, $\nu+2$, $\nu+4$, $\nu+6$, . . . by third, fifth, seventh powers, ...

The second equation of (7) and the second equation of (8), containing as they do in their numerators the first and fifth powers of ν, $\nu+2$, $\nu+4$, $\nu+6$, suggest an intermediate equation

$$\frac{\nu^3}{\nu.\nu+1.\nu+2.\nu+3} - 3\,\frac{(\nu+2)^3}{\nu+1.\nu+2.\nu+3.\nu+4} + 3\,\frac{(\nu+4)^3}{\nu+2.\nu+3.\nu+4.\nu+5} - \frac{(\nu+4)^6}{\nu+3.\nu+4.\nu+5.\nu+6} = 0.$$

Similarly the third equations of (7), (8) suggest intermediate equations

$$\frac{\nu^3}{\nu.\nu+1\ldots\nu+4} - 4\,\frac{(\nu+3)^3}{\nu+1\ldots\nu+5} + 6\,\frac{(\nu+4)^3}{\nu+2\ldots\nu+6} - 4\,\frac{(\nu+6)^3}{\nu+3\ldots\nu+7} + \frac{(\nu+8)^3}{\nu+4\ldots\nu+8} = 0$$

$$\frac{\nu^5}{\nu.\nu+1\ldots\nu+4} - 4\,\frac{(\nu+2)^5}{\nu+1\ldots\nu+5} + 6\,\frac{(\nu+4)^5}{\nu+2\ldots\nu+6} - 4\,\frac{(\nu+6)^5}{\nu+3\ldots\nu+7} + \frac{(\nu+8)^5}{\nu+4\ldots\nu+8} = 0.$$

These formulae can be verified by direct analysis, but we propose to consider them as special cases of more general formulae, first remarking that the two sets (7), (8), together with the supplementary formulae just considered, can be blended into a more comprehensive system, for which it is sufficient to write down in each case the first two terms. This system is

$$\left.\begin{array}{ll}
\text{(i)} & \left\{\begin{array}{ll}
\dfrac{\nu}{\nu.\nu+1.\nu+2} - 2\,\dfrac{\nu+2}{\nu+1.\nu+2.\nu+3}\ \ldots & =0 \\
\dfrac{\nu^3}{\nu.\nu+1.\nu+2} - 2\,\dfrac{(\nu+2)^3}{\nu+1.\nu+2.\nu+3}\ \ldots & =0
\end{array}\right. \\
\text{(ii)} & \left\{\begin{array}{ll}
\dfrac{\nu}{\nu.\nu+1.\nu+2.\nu+3} - 3\,\dfrac{\nu+2}{\nu+1.\nu+2.\nu+3.\nu+4}\ \ldots & =0 \\
\dfrac{\nu^3}{\nu.\nu+1.\nu+2.\nu+3} - 3\,\dfrac{(\nu+2)^3}{\nu+1.\nu+2.\nu+3.\nu+4}\ \ldots & =0 \\
\dfrac{\nu^5}{\nu.\nu+1.\nu+2.\nu+3} - 3\,\dfrac{(\nu+2)^5}{\nu+1.\nu+2.\nu+3.\nu+4}\ \ldots & =0
\end{array}\right. \\
\text{(iii)} & \left\{\begin{array}{ll}
\dfrac{\nu}{\nu.\nu+1.\nu+2.\nu+3.\nu+4} - 4\,\dfrac{\nu+2}{\nu+1.\nu+2.\nu+3.\nu+4.\nu+5}\ \ldots & =0 \\
\dfrac{\nu^3}{\nu.\nu+1.\nu+2.\nu+3.\nu+4} - 4\,\dfrac{(\nu+2)^3}{\nu+1.\nu+2.\nu+3.\nu+4.\nu+5}\ \ldots & =0 \\
\dfrac{\nu^5}{\nu.\nu+1.\nu+2.\nu+3.\nu+4} - 4\,\dfrac{(\nu+2)^5}{\nu+1.\nu+2.\nu+3.\nu+4.\nu+5}\ \ldots & =0 \\
\dfrac{\nu^7}{\nu.\nu+1.\nu+2.\nu+3.\nu+4} - 4\,\dfrac{(\nu+2)^7}{\nu+1.\nu+2.\nu+3.\nu+4.\nu+5}\ \ldots & =0
\end{array}\right.
\end{array}\right\} \quad (9)$$

Two questions which suggest themselves immediately are:

(i) Why are the numerators of (9) always *odd* powers of ν, $\nu+2$, $\nu+4$, . . . ?

(ii) Can the system (9) be still further extended by introducing higher powers of ν, $\nu+2$, $\nu+4$, . . . than those actually employed in the sub-systems of 2, 3, 4, . . . formulae respectively?

Let us first generalize the expressions on the left-hand side of the first sub-system of (9) by replacing them by

$$\frac{\nu^{m+1}}{\nu.\nu+1.\nu+2} - 2\,\frac{(\nu+2)^{m+1}}{\nu+1.\nu+2.\nu+3} + \frac{(\nu+4)^{m+1}}{\nu+2.\nu+3.\nu+4} \qquad (10)$$

where $m=0, 1, 2, 3, \ldots$. The expression, on reduction to a common

denominator, takes the form

$$\frac{\nu^m(\nu+3)-2(\nu+2)^{m+1}+(\nu+1)\ (\nu+4)^m}{\nu+1.\nu+2.\nu+3}$$

The numerator has the factors $\nu+1$, $\nu+2$, $\nu+3$ *if m is even*, as is seen at once by putting $\nu=1, -2, -3$. Hence the fraction (10) is only a fraction in appearance, but in reality a polynomial, *provided m is even.* This gives the answer to (i.). Furthermore the expression (10), when treated by the method of partial fractions, must have no fractional parts but only an integral part of order $m-2$.

Let us next consider the generalization of the polynomials in the second sub-system, namely:

$$\frac{\nu^{m+1}}{\nu.\nu+1.\nu+2.\nu+3} - 3\ \frac{(\nu+2)^{m+1}}{\nu+1.\nu+2.\nu+3.\nu+4} + 3\ \frac{(\nu+4)^{m+1}}{\nu+2.\nu+3.\nu+4.\nu+5} - \frac{(\nu+6)^{m+1}}{\nu+3.\nu+4.\nu+5.\nu+6}$$

$$\equiv \frac{\nu^m(\nu+4)\ (\nu+5)-3(\nu+2)^{m+1}(\nu+5)+3(\nu+1)\ (\nu+4)^{m+1}-(\nu+1)(\nu+2)\ (\nu+6)^m}{\nu+1.\nu+2.\nu+3.\nu+4.\nu+5} \qquad (11)$$

The numerator, *if m is even*, has $\nu+1$, $\nu+2$, $\nu+3$, $\nu+4$, $\nu+5$ as factors. It is desirable to prove this by a method which will apply, mutatis mutandis, to the most general case where the expression to be discussed is of the form

$$\frac{\nu^{m+1}}{\nu.\nu+1\ \ldots\ \nu+n} - n\ \frac{(\nu+2)^{m+1}}{\nu+1.\nu+2\ \ldots\ \nu+n+1} + \frac{n\,(n-1)}{2!}\ \frac{(\nu+4)^{m+1}}{\nu+2.\nu+3\ \ldots\ \nu+n+2} + \ldots \qquad (12)$$

By the ordinary process associated with partial fractions, we have for the fractional parts (omitting for brevity the integral parts)

$$\left.\begin{aligned} \text{(I)}\quad & \frac{\nu^{m+1}}{\nu.\nu+1.\nu+2.\nu+3.\nu+4} = {}^*+ \\ & \frac{(-1)^m}{1.2.3}\ \frac{}{\nu+1} + \frac{(-1)^m 2^m}{-1.1.2}\ \frac{}{\nu+2} + \frac{(-1)^m 3^m}{-2.-1.1}\ \frac{}{\nu+3} + \frac{(-1)^m 4^m}{-3.-2-1}\ \frac{}{\nu+4} \\ \text{(II)}\quad & -4\ \frac{(\nu+2)^{m+1}}{\nu+1.\nu+2\ \ldots\ \nu+5} = \\ & -4\left[\frac{1}{2.3.4}\ \frac{}{\nu+1} + {}^*+ \frac{(-1)^m}{-2.1.2}\ \frac{}{\nu+3} + \frac{(-1)^m 2^m}{-3.-1.1}\ \frac{}{\nu+4} + \frac{(-1)^m 3^m}{-4.-2.-1}\ \frac{}{\nu+5}\right] \end{aligned}\right\} \qquad (13)$$

$$
\begin{aligned}
&\text{(III)}\quad 6\,\frac{(\nu+4)^{m+1}}{\nu+2.\nu+3\;.\;.\;.\;\nu+6} = \\
&\qquad 6\left[\frac{2^m}{\underset{\nu+2}{1.3.4}} + \frac{1}{\underset{\nu+3}{-1.2.3}} + *+ \frac{(-1)^m}{\underset{\nu+5}{-3.-2.1}} + \frac{(-1)^m 2^m}{\underset{\nu+6}{-4.-3.-1}}\right] \\
&\text{(IV)}\quad 4\,\frac{(\nu+6)^{m+1}}{\nu+3.\nu+4.\nu+5.\nu+6.\nu+7} = \\
&\qquad 4\left[\frac{3^m}{\underset{\nu+3}{1.2.4}} + \frac{2^m}{\underset{\nu+4}{-1.1.3}} + \frac{1}{\underset{\nu+5}{-2.-1.2}} + *+ \frac{(-1)^m}{\underset{\nu+7}{-4.-3.-2}}\right] \\
&\text{(V)}\quad \frac{(\nu+8)^{m+1}}{\nu+4.\nu+5.\nu+6.\nu+7.\nu+8} = \\
&\qquad \left[\frac{4^m}{\underset{\nu+4}{1.2.3}} + \frac{3^m}{\underset{\nu+5}{-1.1.2}} + \frac{2^m}{\underset{\nu+6}{-2.-1.1}} + \frac{1}{\underset{\nu+7}{-3.-2.-1}}\right]
\end{aligned}
\qquad (13)
$$

On addition the fractions all vanish. The proof consists in showing that

the $\nu+1$−residues in I, II are equal and opposite,

the $\nu+2$−residues in I, III are equal and opposite,

the $\nu+3$−residues in I, IV, as also in II, III are equal and opposite,

the $\nu+4$−residues in I, V, as also in II, IV are equal and opposite,

the $\nu+5$−residues in II, V, as also in III, IV are equal and opposite.

etc. This proof rests on elementary considerations and need not be given here. In all cases, where m is even, the fractions cancel out.

Let us now consider the case where the integral part, as distinguished from the fractions, drops out. To take first a simple case let us examine the numerator of (11). Its apparent order is $m+2$ and this will be less than the degree 5 of the denominator if $m=0,2$; but the third formula in the second sub-system of (9) shows that $m=4$ also provides a zero result, which at first sight clashes with the fact that the order of the numerator exceeds that of the denominator by 1, and that, therefore, there should be, after division, an integral part of order 1.

The explanation is that the true order of the numerator is not $m+2$ but m, for the coefficient of ν^{m+2} is $1-3+3-1$, $=0$, and that of ν^{m+1} is

$$(4+5)-3(m+1)2-3.5+3(m+1)4+3-m.6-3,\ =0.$$

The inequality $m+2<5$ must accordingly be replaced by $m<5$, and we see that 4 is also a permissible value for the even number m. This

accounts for the presence of *three* formulae in the second sub-system of (9).

There is a precisely similar explanation for the presence of *four* formulae in the third sub-system of (9).

The numerator for the reduced fraction built up from the five components of (13) is

$$\begin{array}{r|l} \nu+5.\nu+6.\nu+7 & (\nu+0)^m \\ -4.\nu+2.\nu+6.\nu+7 & (\nu+2)^m \\ +6.\nu+1.\nu+4.\nu+7 & (\nu+4)^m \\ -4.\nu+1.\nu+2.\nu+6 & (\nu+6)^m \\ +\ \nu+1.\nu+2.\nu+3 & (\nu+8)^m \end{array} \qquad (14)$$

and the denominator is $\nu+1.\nu+2 \ . \ . \ . \ . \ \nu+7$.

The apparent order of the numerator is $m+3$. The requirement for a zero value of the reduced fraction embodied in the inequality $m+3<7$ furnishes only the values $m=0$, 2, whereas $m=4$, 6 are known to be admissible from the third sub-system of (9). The explanation is that the polynomial (14) contains no terms in ν^{m+3}, ν^{m+2}, ν^{m+1}, ν^m; its true order is $m-1$ and the inequality $m+3<7$ has to be replaced by $m-1<7$ thus admitting the further values $m=4$, $m=6$. In this way we have accounted for the four formulae in the third sub-system of (9).

The manner in which it comes about that the terms in ν^{m+3}, ν^{m+2}, ν^{m+1}, ν^m disappear can possibly be best appreciated by the following analysis:

Expanding the terms in the right-hand column of (14) we get

$$\nu^m \text{ (sum of the left-hand column)} + m\nu^{m-1} \left| \begin{array}{l} -4.\nu+2.\nu+6.\nu+7.2 \\ +6.\nu+1.\nu+4.\nu+7.4 \\ -4.\nu+1.\nu+2.\nu+6.6 \\ +\ \nu+1.\nu+2.\nu+3.8 \end{array} \right|$$

$$+ \frac{m(m-1)}{2!}\nu^{m-2} \left| \begin{array}{l} -4.\nu+2.\nu+6.\nu+7.2^2 \\ +6.\nu+1.\nu+4.\nu+7.4^2 \\ -4.\nu+1.\nu+2.\nu+6.6^2 \\ +\ \nu+1.\nu+2.\nu+3.8^2 \end{array} \right|$$

$$+ \frac{m(m-1)(m-2)}{3!}\nu^{m-3} \left| \begin{array}{l} -4.\nu+2.\nu+6.\nu+7.2^3 \\ +6.\nu+1.\nu+4.\nu+7.4^3 \\ -4.\nu+1.\nu+2.\nu+6.6^3 \\ +\ \nu+1.\nu+2.\nu+3.8^3 \end{array} \right|$$

+terms in ν of orders lower than the m^{th}.

Now the coefficient of ν^m in the first term is zero; the coefficient of $m\nu^{m-1}$ is without the terms ν^3, ν^2, ν (and has the value -240); the

coefficient of $\frac{m(m-1)}{2!}\nu^{m-2}$ is without the terms ν^3, ν^2 (and has the value 480ν); the coefficient of $\frac{m(m-1)(m-2)}{3!}\nu^{m-3}$ is without the term ν^3 (and has the value $-18\nu^2+36\nu-24$). It follows that the highest power of ν that actually occurs is the $(m-1)^{\text{th}}$. In other words there are no terms in ν^{m+3}, ν^{m+2}, ν^{m+1}, ν^m.

The coefficients of ν^m, $m\nu^{m-1}$, $\frac{m(m-1)}{2!}\nu^{m-2}$, etc., are in appearance cubic polynomials. The conditions for the vanishing of the term in ν^3 in the first four of these cubics are given by

$$1.0^\alpha-4.1^\alpha+6.2^\alpha-4.3^\alpha+1.4^\alpha=0 \quad (\alpha=0, 1, 2, 3)$$

a special case of the general formula

$$1.0^\alpha-n.1^\alpha+\frac{n(n-1)}{2!}.2^\alpha\ldots.+1.n^\alpha=0 \quad (\alpha=0, 1, 2, 3, \ldots, n-1) \qquad (15)$$

which can be deduced immediately from the identity

$$1.e^{0x}-ne^x+\frac{n(n-1)}{2!}e^{2x}-\ldots+(-1)^n e^{nx}=(1-e^x)^n$$
$$=P_n(x)$$

where $P_n(x)$ is a power series beginning with the term x^n.

It may be worth while to indicate one method of proof of the vanishing of the terms in ν^2 in the second and third cubics, because it also depends on (15).

We have to show that

$$-4(2+6+7)2^\alpha+6(1+4+7)4^\alpha-4(1+2+6)6^\alpha+(1+2+3)8^\alpha \quad (\alpha=1, 2)$$

This may be written

$$6[-4.2^\alpha+6.4^\alpha-4.6^\alpha+1.8^\alpha]$$
$$+3[-4.2^\alpha.3+6.4^\alpha.2-4.6^\alpha.1].$$

The first line vanishes by reason of (15), the second line is zero in virtue of the identity

$$-4.1^\alpha.3+6.2^\alpha.2-4.3^\alpha.1=0 \quad (\alpha=1, 2)$$

which can be regarded as a special case of the general identity

$$1.0^\alpha.n-n.1^\alpha.n-1+\frac{n(n-1)}{2!}.2^\alpha.n-2-\frac{n(n-1)(n-2)}{3!}.3^\alpha.n-3$$
$$+\ldots.+1.n^\alpha.0=0 \quad (\alpha=1, 2, \ldots, n-2).$$

This can be written

$$n\left[1.0^{a}-n.1^{a}+\frac{n(n-1)}{2!}2^{a}-\frac{n(n-1)\ (n-2)}{3!}3^{a}+\ldots\right]$$

$$+\left[n\,1.0^{a+1}-n.1^{a+1}+\frac{n(n-1)}{2!}2^{a+1}-\frac{n(n-1)\ (n-2)}{3!}3^{a+1}+\ldots.\right]$$

and its verification is effected immediately by the use of (15).

We shall now state the general theorem indicated by the preceding analysis.

Theorem.—Reverting to the general expression (12), *the numerator of the reduced fraction*

$$\begin{aligned}
&\nu^{m}(\nu+n+1)\ (\nu+n+2)\ \ldots\ (\nu+2n-1)\\
&-n(\nu+2)^{m+1}\ (\nu+n+2)\ (\nu+n+3)\ \ldots\ (\nu+2n-1)\\
&+\frac{n(n-1)}{2!}(\nu+1)\ (\nu+4)^{m+1}\ (\nu+n+3)\ \ldots\ (\nu+2n-1)\\
&-\quad .\quad .\quad .\quad .\quad .\quad .\quad -\\
&.\quad .\quad .\quad .\quad .\quad .\quad .\quad .\quad .\quad .\\
&+(-1)^{n}\ (\nu+1)\ (\nu+2)\ldots.(\nu+n-1)\ (\nu+2n)^{m},
\end{aligned}$$

though apparently of the order $m+n-1$, *is in reality of the order* $m-1$.

It vanishes for $\nu=-1,\ -2,\ \ldots\ldots,\ -(2n-1)$ *provided* m *is even; if the order* $m-1$ *of the polynomial is less than* $2n-1$, *the polynomial vanishes identically. Accordingly the expression* (12) *is zero when* m *takes any one of the* n *values* 2, 4, ..., $2n-2$. *The sub-systems* (i.), (ii.), (iii). *of* (9) *correspond to the cases* $n=2,\ 3,\ 4$.

This theorem furnishes the answer to the second of the two questions that we have had in view. The sub-systems of (9) are complete.

It appears to be difficult to provide an absolutely direct algebraic proof of the reduction of the numerator's order from $m+n-1$ to $m-1$, but we can convince ourselves of the truth of the theorem by the use of the method employed by Nielsen (l.c. p. 301).

Nielsen defines X_n^r to mean

$$X_n^r=\frac{\nu^{2r-1}}{\nu.\nu+1\ \ldots\ \nu+n}-n\,\frac{\overline{\nu-2}^{2r-1}}{\nu+1.\nu+2\ldots\nu+n+1}+\frac{n(n-1)}{2!}\,\frac{(\nu+4)^{2r-1}}{\nu+2.\nu+3\ldots\nu+n+2}-\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(16)$$

where r ranges from 1 to n.

The system (9) will be supposed to be supplemented by a preliminary formula

$$\frac{\nu}{\nu.\nu+1} - 1.\frac{\nu+2}{\nu+1.\nu+2} = 0$$

forming the first sub-system. What have hitherto been called the 1st, 2nd, 3rd, ... sub-systems will now rank as the 2nd, 3rd, 4th, ... sub-systems. The system (9) so extended can be represented by

$$\left.\begin{aligned} &X_1^1 = 0; \\ &X_2^1 = 0,\ X_2^2 = 0; \\ &X_3^1 = 0,\ X_3^2 = 0,\ X_3^3 = 0; \\ &X_4^1 = 0,\ X_4^2 = 0,\ X_4^3 = 0,\ X_4^4 = 0 \\ &\quad .\quad .\quad .\quad .\quad .\quad .\quad . \end{aligned}\right\} \qquad (17)$$

These X's are interconnected (see Nielsen, l.c., p. 301).

Nielsen has shown, by a very elegant method, that

$$X_n^n = (\nu+2n)^2\, X_n^{n-1},\ X_n^{n-1} = (\nu+2n)^2\, X_n^{n-2}, \text{ etc.},$$

so that $X_n^n = (\nu+2n)^{2^n-2}\, X_n^1$. By proving that the first member X_n^1 of the X_n—sub-system in (17) vanishes, he proves at the same time that X_n^2, X_n^3, ... up to X_n^n also vanish.

The character of his analysis can be appreciated most readily by considering a particular example. Suppose, for instance, that we desire to know a relation connecting X_3^3 and X_3^2 with X_2^2. We have

$$X_3^3 = \frac{\nu^5}{\nu.\nu+1.\nu+2.\nu+3} - 3\frac{(\nu+2)^5}{\nu+1.\nu+2.\nu+3.\nu+4} + 3\frac{(\nu+4)^5}{\nu+2.\nu+3.\nu+4.\nu+5} - \frac{(\nu+6)^5}{\nu+3.\nu+4.\nu+5.\nu+6}$$

$$X_3^2 = \frac{\nu^4}{\nu.\nu+1.\nu+2.\nu+3} - 3\frac{(\nu+2)^3}{\nu+1.\nu+2.\nu+3.\nu+4} + 3\frac{(\nu+4)^3}{\nu+2.\nu+3.\nu+4.\nu+5} - \frac{(\nu+6)^3}{\nu+3.\nu+4.\nu+5.\nu+6}.$$

Multiply X_3^2 by $(\nu+6)^2$, where $\nu+6$ is the last number of the set $\nu, \nu+2, \nu+4, \ldots$ that occurs in X_3^2, and subtract X_3^3 from the product. Hence

$$(\nu+6)^2X_3^2-X_3^3=\frac{\nu^3(\overline{\nu+6}^2-\nu^2)}{\nu.\nu+1.\nu+2.\nu+3}-3\frac{\overline{\nu+2}^3(\overline{\nu+6}^2-\overline{\nu+2}^2)}{\nu+1.\nu+2.\nu+3.\nu+4}$$

$$+3\frac{\overline{\nu+4}^3\ (\overline{\nu+6}^2-\overline{\nu+4}^2)}{\nu+2.\nu+3.\nu+4.\nu+5}$$

$$=\frac{12\nu^3(\nu+3)}{\nu.\nu+1.\nu+2.\nu+3}-3\frac{8\,(\nu+2)^3\,(\nu+4)}{\nu+1.\nu+2.\nu+3.\nu+4}+3\frac{4(\nu+4)^3\,(\nu+5)}{\nu+2.\nu+3.\nu+4.\nu+5}$$

$$=12\left[\frac{\nu^3}{\nu.\nu+1.\nu+2}-2\frac{(\nu+2)^3}{\nu+1.\nu+2.\nu+3}+\frac{(\nu+4)^3}{\nu+2.\nu+3.\nu+4}\right]$$

$$=12\,X_2^2$$

Notice how the reduction from the fifth to the third powers of ν, $\nu+2$, $\nu+4$ is effected; also the manner in which the denominators with four factors pass into denominators with three factors, and finally the simultaneous conversion of the binomial coefficients 1, 3, 3, 1 into the binomial coefficients 1, 2, 1.

Suppose now that $r > n$ in X_n^r. Nielsen has not occasion to consider this case, but his analysis applies here also. The X's will no longer vanish; moreover we know that when X_n^r is expressed in partial fractions, these partial fractions drop out leaving only an integral part. The order of this integral part, putting $m=2(r-1)$, should apparently be $(m+n-1)-(2n-1)$, $=m-n$, but is actually $m-2n$, owing to the vanishing, in the numerator of the reduced fraction X_n^r, of the n terms x^m, x^{m+1}, ... , x^{m+n-1}.

The method for proving this need not be worked out in full; the essential parts of the proof can be derived readily from the study of particular examples.

For instance $X_3^4=(\nu+6)^2\,X_3^3-12X_2^3=-12X_2^3$,

$$X_2^3=(\nu+4)^2X_2^2-8X_1^2=-8X_1^2,$$

$$X_1^2=-4$$

so that $X_3^4=12.8X_1^2=-12.8.4$

$$X_2^3=8.4.$$

For X_3^4, m takes the value 6 and $n=3$; hence $m-n=0$ and the integral part should reduce to a constant, as is in fact the case.

Again

$$X_3^5=(\nu+6)^2X_3^4-12X_2^4=-12.8.4(\nu+6)^2-12X_2^4;$$

$$X_2^4=(\nu+4)^2X_2^3-8X_1^3=8.4(\nu+4)^2-8X_1^3$$

$$X_1^3=-8(\nu^2+2\nu+2),$$

so that X_3^5 is a quadratic in ν. By the theorem, since $m=8$, $n=3$, the order of the integral part should be $m-2n=8-6=2$, as is in fact the case.

AN APPLICATION OF LIE'S THEOREM ON THE TORSION OF A COMPLEX CURVE

By Charles T. Sullivan, Ph.D., D.Sc.; F.R.S.C.

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Introduction

A curve is said to belong to a linear complex or, more briefly, to be a complex curve, if all of its tangents are lines of a linear complex. All complex curves through a point have a common osculating plane at the point, viz., the polar plane of the point for the complex. It has been shown by Lie that the torsion of a complex curve at a point is a function of the constants of the complex and the co-ordinates of the point only; and, therefore, the same for each complex curve through the point.*. In the succeeding pages it is proposed to apply this theorem on the torsion of a complex curve to show that: If one family of the parametric curves on a surface determined by Lelieuvre's Integrals are complex curves, it is necessary and sufficient that the Lelieuvre Integrals be constructed from a Moutard equation of range three at most.

We shall first develop certain formulae required in this discussion. If $\theta_1, \theta_2, \theta_3$ be three linearly independent solutions of the Moutard equation

$$\text{(A)} \qquad \frac{\partial^2\theta}{\partial p\,\partial q} = \lambda(p, q)\,\theta,$$

then the parametric curves on the surface determined by the Lelieuvre Integrals

$$\text{(S)} \qquad x = \int\left(\theta_2\frac{\partial\theta_3}{\partial p}\right)dp - \left(\theta_2\frac{\partial\theta_3}{\partial q}\right)dq,$$

$$y = \int\left(\theta_3\frac{\partial\theta_1}{\partial p}\right)dp - \left(\theta_3\frac{\partial\theta_1}{\partial q}\right)dq,$$

$$z = \int\left(\theta_1\frac{\partial\theta_2}{\partial q}\right)dp - \left(\theta_1\frac{\partial\theta_2}{\partial q}\right)dq,$$

are asymptotic curves on the surface (Eisenhardt—Differential Geometry, p. 194).

* Proceedings of the Society of Science at Christiania (1883).

From equations (A) and (S), we find at once

$$x_1=\left(\theta_2\frac{\partial\theta_3}{\partial p}\right),\ x_2=-\left(\theta_2\frac{\partial\theta_3}{\partial q}\right),$$

$$(1)\qquad x_{11}=\left(\theta_2\frac{\partial^2\theta_3}{\partial p^2}\right),\ x_{22}=-\left(\theta_2\frac{\partial^2\theta_3}{\partial q_2}\right),$$

$$x_{12}=\left(\frac{\partial\theta_2}{\partial q}\ \frac{\partial\theta_3}{\partial p}\right)+\left(\theta_2\frac{\partial^2\theta_3}{\partial p\,\partial q}\right)=\left(\frac{\partial\theta_2}{\partial q}\ \frac{\partial\theta_3}{\partial p}\right),$$

by virtue of (A),

where

$$x_1=\frac{\partial x}{\partial p},\ x_2=\frac{\partial x}{\partial q},\ x_{12}=\frac{\partial^2 x}{\partial p\,\partial q},\ \text{etc.}$$

The corresponding formulae for y and z can be obtained from these by introducing the proper pair of the three solutions $\theta_1, \theta_2, \theta_3$.

If the fundamental magnitudes of the first and second orders of the surface (S) be denoted by E, F, G and L, M, N respectively, we find immediately from the definitions of these quantities and from equations (1) the following relations:

$$(2)\quad E=\Sigma\left(\theta_1\frac{\partial\theta_2}{\partial p}\right)^2,\ F=-\Sigma\left(\theta_1\frac{\partial\theta_2}{\partial p}\right)\left(\theta_1\frac{\partial\theta_2}{\partial q}\right),\ G=\Sigma\left(\theta_1\frac{\partial\theta_2}{\partial q}\right)^2,$$

$$L=O,\ MV=\left(\left(\theta_2\frac{\partial\theta_3}{\partial p}\right)\left(\theta_3\frac{\partial\theta_1}{\partial q}\right)\right)\frac{\partial\theta_1}{\partial p}\ \frac{\partial\theta_2}{\partial q}\Big)\Big),\ N=O,$$

where

$$V^2=E\,G-F^2.$$

In order to reduce these expressions to their simplest forms, we make use of two formulae from the theory of determinants, viz.:

$$(3)\qquad \begin{vmatrix} a^2+b^2+c^2 & aa'+bb'+cc' \\ aa'+bb'+cc' & a'^2+b'^2+c'^2 \end{vmatrix} = \Sigma \begin{vmatrix} a & b \\ a' & b' \end{vmatrix}^2,$$

and

$$(4)\qquad \Sigma \begin{vmatrix} B' & C' \\ B'' & C'' \end{vmatrix} = (a+b+c)\,D,$$

where B', B'', etc. are the minors of b', b'', etc. in the determinant

$$D=\begin{vmatrix} a & b & c \\ a' & b' & c' \\ a'' & b'' & c'' \end{vmatrix}.$$

From the realtions (2) and (3), we derive:

$$V^2 = EG - F^2 = \begin{vmatrix} \Sigma\left(\theta_1 \frac{\partial\theta_2}{\partial p}\right)^2 & -\Sigma\left(\theta_1 \frac{\partial\theta_2}{\partial p}\right)\left(\theta_1 \frac{\partial\theta_2}{\partial q}\right) \\ -\Sigma\left(\theta_1 \frac{\partial\theta_2}{\partial p}\right)\left(\theta_1 \frac{\partial\theta_2}{\partial q}\right) & \Sigma\left(\theta_1 \frac{\partial\theta_2}{\partial q}\right)^2 \end{vmatrix}$$

$$= \Sigma \begin{vmatrix} \left(\theta_1 \frac{\partial\theta_2}{\partial p}\right) & \left(\theta_2 \frac{\partial\theta_3}{\partial p}\right) \\ \left(\theta_1 \frac{\partial\theta_2}{\partial p}\right) & \left(\theta_2 \frac{\partial\theta_3}{\partial q}\right) \end{vmatrix}^2$$

This expression reduces to

$$(5) \qquad V^2 = (\theta_1^2+\theta_2^2+\theta_3^2)\left(\theta_1 \frac{\partial\theta_2}{\partial p} \frac{\partial\theta_3}{\partial q}\right)^2,$$

by virtue of formula (4).

$$MV = \left(\left(\theta_2 \frac{\partial\theta_3}{\partial p}\right) \left(\theta_3 \frac{\partial\theta_1}{\partial q}\right) \left(\frac{\partial\theta_1}{\partial p} \frac{\partial\theta_2}{\partial q}\right) \right)$$

$$= \left(\theta_1 \frac{\partial\theta_2}{\partial p} \frac{\partial\theta_3}{\partial q}\right)^2, \text{ by an elementary property of determinants.}$$

In this case, the quantity $T^2 = LN - M^2$ reduces to $-M^2$; and the Gauss measure of curvature K has the value

$$(7) \qquad K = \left(\frac{T}{V}\right)^2 = -\frac{1}{(\Sigma\theta^2)^2}.$$

In the customary notation, the direction cosines of the normal to (S) at the point $P(x, y, z)$ are:

$$X, Y, Z = \frac{1}{V} \begin{Vmatrix} x_1 & y_1 & z_1 \\ x_2 & y_2 & z_2 \end{Vmatrix}.$$

On using the relations (1) and (5), these become

$$(8) \qquad X, Y, Z = \frac{\theta_1}{\sqrt{\Sigma\theta^2}}, \frac{\theta_2}{\sqrt{\Sigma\theta^2}}, \frac{\theta_3}{\sqrt{\Sigma\theta^2}}.$$

If now ρ_q, σ_q denote the radius of curvature and the radius of torsion respectively at the point $P(x, y, z)$ on the curve $q = \text{const.}$, then

$$\frac{1}{\rho_q^2} = \Sigma x''^2, \quad \frac{1}{\rho_q^2 \sigma_q} = (x' y'' z'''),$$

Where the primes indicate differentiation with respect to the arc s_q.

Along $q=$const., we have

$$ds_q=\sqrt{E}\,dp,\ x'=\frac{x_1}{\sqrt{E}},\ x''=\frac{x_{11}}{E}-\tfrac{1}{2}\frac{E_1 x_1}{E^2},$$

$$x'''=\frac{1}{\sqrt{E}}\left(\frac{x_{111}}{E}-\tfrac{3}{2}\frac{x_{11}E_1}{E^2}-\tfrac{1}{2}\frac{x_1 E_{11}}{E^2}+\frac{x_1 E_1^2}{E^3}\right),\ \text{etc.}$$

Thus

$$(9)\qquad \frac{1}{\rho_q^2}=\frac{\Sigma x_{11}^2}{E^2}-\tfrac{1}{4}\frac{E_1^2}{E^3}$$

$$=\frac{1}{E^3}\left[\Sigma\left(\theta_2\frac{\partial\theta_3}{\partial p}\right)^2\times\Sigma\left(\theta_2\frac{\partial^2\theta_3}{\partial p^2}\right)^2-\Sigma\left(\theta_2\frac{\partial\theta_3}{\partial p}\right)\left(\theta_2\frac{\partial^2\theta_3}{\partial p^2}\right)\right]$$

$$=\frac{1}{E^3}\,\Sigma\begin{vmatrix}\left(\theta_1\frac{\partial\theta_2}{\partial p}\right) & \left(\theta_2\frac{\partial\theta_3}{\partial p}\right)\\ \left(\theta_1\frac{\partial^2\theta_2}{\partial p^2}\right) & \left(\theta_2\frac{\partial^2\theta_3}{\partial p^2}\right)\end{vmatrix}^2$$

$$=\frac{1}{E^3}(\Sigma\theta^2)\left(\theta_1\frac{\partial\theta_2}{\partial p}\ \frac{\partial^2\theta_3}{\partial p^2}\right)^2,$$

by virtue of formulae (3) and (4).

Again

$$\frac{1}{\rho_q^3\,\sigma_q}=(x'\,y''\,z''')=$$

$$\left(\frac{x_1}{\sqrt{E}},\ \frac{y_{11}}{E}-\tfrac{1}{2}\frac{y_1E_1}{E^2},\ \frac{1}{\sqrt{E}}\left[\frac{z_{111}}{E}-\tfrac{3}{2}\frac{z_{11}E_1}{E^2}-\tfrac{1}{2}\frac{z_1E_1^2}{E^2}+\frac{z_1E_1^2}{E^3}\right]\right)$$

$$=\frac{1}{E^3}(x_1\,y_{11}\,z_{111}).$$

Now form relations (1) and certain evident elementary properties of determinants, we deduce the relation:

$$(x_1\,y_{11}\,z_{111})=\left(\left(\theta_1\frac{\partial\theta_2}{\partial p}\right)\left(\theta_2\frac{\partial^2\theta_3}{\partial p^2}\right)\left(\theta_3\frac{\partial^3\theta_1}{\partial p^3}\right)\right)+$$

$$\left(\left(\theta_1\frac{\partial\theta_2}{\partial p}\right)\left(\theta_2\frac{\partial^2\theta_3}{\partial p^2}\right)\left(\frac{\partial\theta_3}{\partial p}\ \frac{\partial^2\theta_1}{\partial p^2}\right)\right)$$

$$=\left(\theta_1\frac{\partial^2\theta_2}{\partial p^2}\ \frac{\partial^3\theta_3}{\partial p^3}\right)\left(\theta_1\theta_2\frac{\partial\theta_3}{\partial p}\right)+\left(\theta_1\frac{\partial\theta_2}{\partial p}\ \frac{\partial^2\theta_3}{\partial p^2}\right)^2;$$

and, therefore,

$$\frac{1}{\rho_q^2\,\sigma_q} = \frac{1}{E^3}\left(\theta_1 \frac{\partial\theta_2}{\partial p} \frac{\partial^2\theta_3}{\partial p^2}\right)^2. \tag{10}$$

Hence along the curve $q=$const.,

$$\frac{1}{\sigma_q} = \frac{1}{(\Sigma\theta^2)} = +\sqrt{-K}\,,$$ by virtue of equation (7),

if we choose the positive value of the root. With this convention as to signs, we find in a precisely similar manner that

$$\frac{1}{\sigma_p} = -\sqrt{-K},$$

along the curve $p=$const.
Thus

$$\frac{1}{\sigma_p^2} = \frac{1}{\sigma_q^2} = -K, \text{ and } \frac{1}{\sigma_p} = -\frac{1}{\sigma_q}\,,$$

Which is Enneper's theorem on the torsion of the asymptotic curves.

We next consider the one parameter family of linear complexes defined by the equation

$$Sa\,(y\delta z - z\delta y) + S\alpha\,\delta x = 0, \tag{11}$$

where S signifies the cyclic sum over the three axes and a, b, c; α, β, γ are functions of one parameter q. We may, without loss of generality, assume the realtion

$$a\alpha + b\beta + c\gamma = 1. \tag{12}$$

Consider now a point $P\ (x, y, z)$ on the surface (S). Corresponding to this point $P\ (p, q)$ on (S) there is a definite complex of the family (11); let X, Y, Z be the direction cosines of the polar plane of P in this complex. Then from the theory of the linear complex, it follows that

$$\begin{aligned} \sqrt{k}\,X &= \alpha + bz - cy, \\ \sqrt{k}\,Y &= \beta + cx - az, \\ \sqrt{k}\,Z &= \gamma + ay - bx, \end{aligned} \tag{13}$$

where $\sqrt{k}$ is a factor of proportionality. By squaring and adding these equations, we find

$$k = S\,(\alpha + bz - cy)^2.* \tag{14}$$

But the expression on the right hand side of this equation is that found by Lie for the torsion of a complex curve at the point $P\ (x, y, z)$. Thus

*Lie and Sheffers' Berührungs transformationen, p. 233.

$k = \frac{1}{\sigma}$, where σ is the radius of torison of the complex curve at the point.

If now the parametric curves $q = \text{const.}$ on the surface (S) belong to the complexes given by equation (11), and K be the Gauss Measure of Curvature at the point P on (S), then it follows from Enneper's theorem and equation (14) that

$$\frac{1}{\sigma_q} = \sqrt{-K} = S(a + bz - cy)^2. \tag{15}$$

Again from equations (7), (9) and (15), we deduce

$$X = \frac{\theta_1}{\sqrt{\sigma_q}}, \quad Y = \frac{\theta_2}{\sqrt{\sigma_q}}, \quad Z = \frac{\theta_3}{\sqrt{\sigma_q}}, \tag{16}$$

where X, Y, Z are the direction cosines of the normal at the point P (x, y, z) on (S).

Thus

$$\begin{aligned} \theta_1 &= \sqrt{\sigma_q}\, X = a + bz - cy, \\ \theta_2 &= \sqrt{\sigma_q}\, Y = \beta + cx - az, \\ \theta_3 &= \sqrt{\sigma_q}\, Z = \gamma + ay - bx. \end{aligned} \tag{17}$$

These are the equations we require to demonstrate that equation (A) is of range three at most. We must first recall however the steps of a theorem due to Goursat:

Given a linear partial differential equation of the second order

$$\frac{\partial^2\theta}{\partial p\, \partial q} + a(p, q)\frac{\partial\theta}{\partial p} + b(p, q)\frac{\partial\theta}{\partial q} + c(p, q) = 0, \tag{B}$$

if $(n+1)$ linearly independent intetrals are connected by a homogeneous linear relation the coefficients of which are functions of one of the independent variables only, then $n-1$ applications at most of a Laplace transformation will lead to an equation with a vanishing invariant.

First consider the case $n = 1$; then the assumed relation is (say):

$$\theta_2 = U(q)\,\theta_1.$$

If this value of θ_2 be substituted in (B) we shall find:

$$\frac{d\theta_1}{dp} + b\,\theta_1 = 0.$$

Consequently

$$\frac{\partial^2 \theta_1}{\partial p\, \partial q} + b\,\frac{\partial \theta_1}{\partial q} + \theta_1 \frac{\partial b}{\partial q} = 0,$$

and therefore (in virtue of (B)):

$$\theta_1 \frac{\partial b}{\partial q} + \theta_1 c - a\frac{\partial \theta_1}{\partial p} = 0.$$

On substituting the value of $\frac{\partial \theta_1}{\partial p}$ given above in this equation, we find that the invariant $ab + \frac{\partial b}{\partial q} - c$ vanishes.

Again let the assumed relation be

$$\theta_{n+1} = \sum_{i=1}^{n} U_i(q)\,\theta_i.$$

From this relation and (B), we deduce

$$\sum_{i=1}^{n} \frac{\partial U_i}{\partial q} \cdot \left(\frac{\partial \theta_i}{\partial p} + b\,\theta_i\right) = 0.$$

If now we apply to (B) the Laplace transformation defined by

$$\theta' = \frac{\partial \theta}{\partial p} + b\,\theta,$$

the transformed equation (B′) will have n solutions $\theta_i'(i=1, \ldots, n)$ connected by the relation

$$\theta_n' = \sum_{i=1}^{n-1} U_i'(q)\,\theta_i'.$$

Thus after $n-1$ applications of this transformation, we shall arrive at an equation having two solutions $\theta_1^{(n-1)}$, $\theta_2^{(n-1)}$ connected by the relation

$$\theta_2^{(n-1)} = U^{(n-1)}(q)\;\theta_1^{(n-1)},$$

and by the first part of the theorem, it has a vanishing invariant

$$a^{(n-1)}\,b^{(n-1)} + \frac{\partial b^{(n-1)}}{\partial q} - c^{(n-1)}.$$

Equations (12) and (17) lead to the relations

$$a\theta_1 + b\theta_2 + c\theta_3 = a\alpha + b\beta + c\gamma = 1, \tag{18}$$

and therefore

$$a\,\frac{\partial\theta_1}{\partial p} + b\,\frac{\partial\theta_2}{\partial p} + c\,\frac{\partial\theta_3}{\partial p} = 0\,.$$

The Laplace transformation defined above reduces to $\theta' = \dfrac{\partial\theta}{\partial p}$ for equation (A). Hence, if to (A) we apply this transformation, there results an equation (A′) having three solutions θ_1', θ_2', θ_3' connected by the relation

$$a'(q)\,\theta_1' + b'(q)\,\theta_2' + c'(q)\,\theta_3' = 0.$$

Then by the theorem outlined above, two applications of a Laplace transformation leads to an equation (A″) having a vanishing invariant

$$\left[\lambda - \frac{\partial^2 \log}{\partial p\,\partial q}\left(\lambda^2\,\overline{\lambda - \frac{\partial^2 \log \lambda}{\partial p\,\partial q}}\right)\right].$$

Thus, if either family of the asymptotic curves of (S) be complex curves, it is necessary that the Moutard equation (A) be of range three at most. This condition is also sufficient. Because, if (A) be of range three, we can select three linearly independent solutions θ_1, θ_2, θ_3 connected by the relation (18). Hence we have the two relations

(19)
$$a\theta_1 + b\theta_2 + c\theta_3 = 1\,,$$

$$a\,\frac{\partial\theta_1}{\partial p} + b\,\frac{\partial\theta_2}{\partial p} + c\,\frac{\partial\theta_3}{\partial p} = 0\,.$$

From these we deduce

(20)
$$\frac{\partial\theta_1}{\partial p} = b\left(\theta_2\frac{\partial\theta_1}{\partial p} - \theta_1\frac{\partial\theta_2}{\partial p}\right) + c\left(\theta_3\frac{\partial\theta_1}{\partial p} - \theta_1\frac{\partial\theta_3}{\partial p}\right),$$

$$\frac{\partial\theta_2}{\partial p} = c\left(\theta_3\frac{\partial\theta_2}{\partial p} - \theta_2\frac{\partial\theta_3}{\partial p}\right) + a\left(\theta_1\frac{\partial\theta_2}{\partial p} - \theta_2\frac{\partial\theta_1}{\partial p}\right),$$

$$\frac{\partial\theta_3}{\partial p} = a\left(\theta_1\frac{\partial\theta_3}{\partial p} - \theta_3\frac{\partial\theta_1}{\partial p}\right) + b\left(\theta_2\frac{\partial\theta_3}{\partial p} - \theta_3\frac{\partial\theta_2}{\partial p}\right).$$

If cognizance be taken of equations (1), these become

(21)
$$\frac{\partial\theta_1}{\partial p} = cy_1 - bz_1\,,$$

$$\frac{\partial\theta_2}{\partial p} = az_1 - cx_1\,,$$

$$\frac{\partial \theta_3}{\partial p} = bx_1 - ay_1.$$

Whence

(22)
$$\theta_1 = cy - bz + \alpha,$$
$$\theta_2 = az - cx + \beta,$$
$$\theta_3 = bx - ay + \gamma,$$

where α, β, γ are arbitrary functions of q. But these equations show that the parametric curve $q=$const. belongs to the complex.

$$Sa\,(y\,\delta z)+S\alpha\,\delta x=0.$$

Let us next consider the tangents to the curves $p=$const. along a curve $q=$const. If for δx, δy, δz we substitute $\frac{l}{\sqrt{G}}x_2$, $\frac{l}{\sqrt{G}}y_2$, $\frac{l}{\sqrt{G}}y_2$, we see that these tangents belong to the complex of (11) corresponding to the value of q considered. In a similar manner we find that the tangents to the curves $p=$const. along the curve $q+\delta q$ belong to the complex

$$\{Sa(y\,\delta z-z\,\delta y)+S\alpha\,\delta x\}+\delta q\,\{Sa'\,(y\,\delta z-z\,\delta y)+S\alpha'\,\delta x\}=0,$$

where the primes indicate differentiation with respect to q. Thus the tangents to the curves $p=$const. are all contained in the complex obtained by eliminating q between the equations

$$Sa\,(y\,dz-z\,\delta y)+S\alpha\,\delta x=0,$$
$$Sa'(y\,\delta z-z\,\delta y)+S\alpha'\,\delta x=0,$$

that is, the enveloping complex of the family defined by (11). This result was given by Lie in reference cited above.

Finally we consider a surface (S) for which both families of parametric curves are complex curves. It follows from the results established above that the solutions θ_1, θ_2, θ_3 of (A) must satisfy the two relations.

(23)
$$a\,(q)\,\theta_1+b\,(q)\,\theta_2+c\,(q)\,\theta_3=1,$$
$$\overline{a}\,(p)\,\theta_1+\overline{b}\,(p)\,\theta_2+\overline{c}\,(p)\,\theta_3=1.$$

The two families of complexes are then defined by the equations

(24)
$$Sa(y\,\delta z-z\,\delta y)+S\alpha\,\delta x=0,$$
$$S\overline{a}\,(y\,\delta z-z\,\delta y)+S\overline{\alpha}\,\delta x=0.$$

Following the same line of reasoning as that employed to establish equations (17), we establish the two sets of equations

(25)
$$\frac{\theta_1}{\sqrt{\sigma_q}} = \alpha + bz - cy,$$
$$\frac{\theta}{\sqrt{\sigma_q}} = \beta + cx - az,$$
$$\frac{\theta_3}{\sqrt{\sigma_q}} = \gamma + ay - bx.$$

and

$$-\frac{\theta_1}{\sqrt{\sigma_p}} = \alpha + bz - cy,$$
$$-\frac{\theta_2}{\sqrt{\sigma_p}} = \bar{\beta} + \bar{c}x - \bar{a}z,$$
$$-\frac{\theta_3}{\sqrt{\sigma_p}} = \bar{\gamma} + \bar{a}y - \bar{b}x.$$

From these and equations (23) we deduce

$$S\bar{a}\alpha + Sa\bar{\alpha} = \frac{1}{\sigma_p} + \frac{1}{\sigma_q} = 0,$$

by Enneper's theorem. This is the relation that must be satisfied by the functions $a, b, c, \alpha, \beta, \gamma$; $\bar{a}, \bar{b}, \bar{c}, \bar{\alpha}, \bar{\beta}, \bar{\gamma}$ in order to comply with the conditions of the problem. Geometrically, it expresses that the two families of complexes are in involution.

McGILL UNIVERSITY.

THE INTERPOLATION OF BREAKS IN TIDE CURVES FROM RECORDING GAUGES

To secure continuous record for a complete year at a time, for harmonic analysis.

By W. Bell Dawson, M.A., D.Sc., M.Inst.C.E., F.R.S.C.

[redacted]

One of the primary ends in view in the investigation of the tides, is the prediction of the time and the height of high and low water for a future year, published in the form of Tide Tables, by which these data for the tide, day by day, may be known. To attain this end, three steps are required: (1) A continuous series of observations in which the height of the water is ascertained moment by moment with relation to the time. Such observations are best obtained by a registering instrument, which gives a record of the tide in the form of a continuous curve. When reduced to a truly uniform datum level, and when all time errors are eliminated, this curve gives the desired correlation of height relatively to time. (2) An analysis of this tide curve, by which a series of primary sinusoids are obtained as its components. These sinusoids are represented by tidal constants which define their phase and amplitude. (3) By re-combining these sinusoids, with their phases set to correspond with the astronomical conditions of any future year, and with amplitudes as found by observation at any given locality, the tide curves for that year can be produced. These are called prediction curves; and from them the time and height of successive high and low waters are read off, to constitute a Tide Table for the year.

For such an analysis, it is essential to have an unbroken series of tidal observations for a complete year at a time. A year is needed to obtain the recurrence of astronomical conditions in the variously related movements of the moon, as well as the solar elements. The year dealt with may begin at any calendar date, however.

If any break or interruption occurs from any cause, or if the observations are faulty or uncertain for a time, it is necesssary to complete or replace the tide curves by some method of interpolation. If this cannot be done, the period of observation up to the break must be set aside and a fresh beginning made, in the endeavour to obtain a complete year for analysis. Interruptions are more probable in winter, especially

at exposed situations where tidal stations are erected for strategic reasons; and if the break cannot be made good, the fine record obtained during the previous summer season may be lost so far as the analysis is concerned; although this record is usually of service for other purposes, such as comparisons between secondary stations and the principal station during the season.

After one or two complete years have been analysed and tidal constants obtained from them, it is theoretically possible to fill a gap by means of the prediction curves. But it can readily be explained why this method is less desirable than an interpolation based on the actual tide curves, as recorded by the registering instrument.

Tidal variations and the Harmonic analysis.—There are three leading variations in the tide which accord with the movements of the moon and the sun; firstly, the variation from Springs to Neaps in accord with the moon's phases in the Synodic month; secondly, a more or less marked change in amplitude which accords with the moon's distance during the Anomalistic month; and thirdly, an inequality between the two tides of the day which follows the moon's Declination and only disappears when the moon is on the equator. In regions where the tide is dominated by declination, the annual motion of the sun north and south of the equator, has also a great influence; and the extreme tides of the year consequently occur in the vicinity of the solstices.

A difficulty which is probably the most serious one in tidal calculation, results from the variation in the range of the moon's declination during a cycle of 19 years. At one extreme of this cycle, the range in declination is from 28° north to 28° south of the equator; while at the other extreme, at the opposite phase of the cycle 9½ years later, the range is only from 18° north to 18° south. Even in other operations, such as the determination of the low-water datum or the comparison of tidal amplitudes, the position of the year in the 19-year cycle may have to be taken into account, when the variations that occur are large.

In the harmonic analysis, the effects of this change in declination can only be allowed for by giving variable values to four of the leading "tidal constants" during the course of the 19-year cycle. But the amount of variation thus allowed at a new locality must be based to begin with upon general theory, and it may be found later to differ considerably from its observed amount; especially in a region where diurnal inequality, due to declination, is the leading feature of the tide. It is evidently undesirable therefore, to introduce prediction curves into the observed series while the variation is under determination; and it is better to accept breaks or spaces between the complete years submitted to analysis; as these years will fall at various points around the 19-year cycle and

thus enable the variation during its course to be correctly determined eventually, from observation alone.

Examples of Interpolation.—The interpolation which we here give as an example, is the filling of gaps which occurred in a tide of this declinational type at its extreme accentuation in January and December near the solstices; and if the method described will answer in such a case, it may safely be taken as a guide for the interpolation of a break in the continuity of tide curves of a less exacting character.

In the Strait of Georgia, the tide is of this type. The curves in the Plates will show its character. There were two gaps in the tidal record from the principal tidal station in that strait during the year 1919; one of nine days in January, and the other of ten days in December. Unless these gaps could be filled, it is evident that at least the eleven months intervening would be lost. If a break in a tidal record occurs when a year is nearly completed, an overlap may be made to obtain 12 consecutive months; but at this station, the complete years for analysis are now running from May to May; and the overlap required would be too large. With the best arrangement possible, the period lost would therefore be be nineteen months; which shows what large losses may be involved if a tidal record cannot be completed.

Methods of Interpolation.—The breaks in the record, for which interpolation is required, may be classed as short and long. If not much over a day, generally because of some slight accident, the missing portion can readily be filled in as a rule, by superposing the curves for successive days and interpolating between them. A difficulty only occurs when the missing part happens to be the maximum or minimum at Spring or Neap tides; or if the curves are disturbed from the normal before and after the break. It is good practice also to replace any severe storm disturbance by an interpolated curve. During a day, or a day and a half, the successive tides may be raised or lowered from one to three feet; and such abnormal curves would only deteriorate accuracy if included in the analysis.

The best method of dealing with long breaks, by which we mean a week or ten days, is what we will now describe. It may be said in general terms to be based on the recurrence of approximately the same form of tide curve after the lapse of a month; and consequently, that it should be possible to make an interpolation between the corresponding days in the previous and following lunar months. The half-month will not do, because the moon's distance varies during the period of a whole month; and successive Spring tides thus usually show a "semi-monthly inequality" which is always appreciable and in some regions is large. But after the lapse of a month, the phases of the moon are not far out of

accord with the declination and the distance, which agree closely with each other. Hence the general principle is that any missing day in the gap, can be interpolated between a pair of curves, drawn on the same sheet, which are for the corresponding days a month previous and a month later.

The true average lengths of the "months" with which we have to deal are as follows, in mean solar days:

Synodic month of the Moon's phases.....29.5306 days
Anomalistic month of the Moon's distance.....27.5545 "
Month of the Moon's declination.....27.3216 "

In dealing with these periods, a difficulty arises at the outset because of the fractional half day in the Synodic month. To obtain an interval equal to the true length of that month before and after any missing day, a preliminary interpolation ought first to be made between the curves at 29 and 30 days before, and 29 and 30 days after; to obtain two curves which represent hypothetical days between the actual days at the proper interval of 29½ days. A final interpolation between this pair of hypothetical days, will then give the missing day required. This method has been tried; and although tedious, it should be satisfactory in dealing with tides in which all other variations are negligeable except those that recur in the period of the Synodic month. But in the more complex problem of Declinational tides, it was found that it was not practicable to adhere strictly to the Synodic month alone; and also that the double work entailed by this preliminary interpolation could be obviated by a different procedure.

It was accepted as a working basis, that some compromise would have to be made between the length of the Synodic and Declinational months. Any variation in the Anomalistic month would thus be dealt with also, as its length is so nearly the same as the Declinational. The actual mean between the periods of the Synodic and Declinational months is 28.43 days, or very nearly 28½ days. The difficulty of a half day reappears. Trial interpolations were accordingly made between pairs of curves at equal intervals before and after any missing day, the interval ranging from 27 to 30 days to cover the various months. It was finally decided to adopt an interval of 29 even days before and after the missing day. This gives somewhat greater weight to the Synodic month, as it is only half a day short of its length; and it is over 1½ days longer than the Declinational month.

When pairs of curves at this interval of 29 days before and after the missing day were placed together on the same sheet, there were times when on the one hand, the pair might be too widely spaced in time to

enable a good interpolation to be made; or on the other, when a large difference in the height of high and low water on the two curves of the pair, made the interpolation uncertain within appreciable limits. This difficulty only occured during one half of the day, however, when the diurnal inequality was large owing to the moon being in high declination at that point in the month. At such times it could not be assumed that a curve exactly midway between the pair, whether in time or in height, would be truly correct in position.

It was evident therefore, that if this compromise interval between the lengths of the months is to be adopted as a basis of interpolation, some method of checking the position of the interoplated curves at the points of high and low water should also be devised. As a rule, it is only necessary as above pointed out, to obtain the co-ordinates of the Higher high water and the Lower low water of the day. The method of computation is on exactly the same system as the double interpolation already described; as will be seen in the table here given. The interval of 28½ days is the actual mean between the periods of the Synodic and Declinational months. It is also to be noted that the computation is based entirely on values read from the recorded curves, and not on prediction values from the Tide Tables.

Dates in 1918 and 1919, and Description	High Water		Low Water	
	Time.	Height	Time.	Height
	H.M.	Feet	H.M.	Feet
Dec. 18.—29 days before the missing day.	6:46	14.6	23:51	0.1
Dec. 19.—28 days before the missing day.	7:26	14.7	24:34	0.7
Values on hypothetical curve, 28½ days before	7:06	14.6	24:12	0.4
Feb. 13.—28 days after the missing day.	5:23	13.7	22:45	2.4
Feb. 14.—29 days after the missing day.	5:53	13.7	23:25	2.9
Values on hypothetical curve, 28½ days after	5:38	13.7	23:05	2.6
Mean of hypothetical values, giving the actual day Jan. 16	6:22	14.2	23:38	1.5

The degree of accuracy of this computation may be tested by the method shown in the first of the tables appended, in which the Synodic

and Declinational months are treated separately, each in its own period. The values for the same missing day (December 17) as obtained by the system adopted, are shown in the table next following. The whole four days, before and after, are here placed together, as the arithmetical result is the same as though they were averaged in pairs. The comparison of the two results shows how very small any error is likely to be.

Possible errors outstanding.—The only remaining sources of appreciable error which seem possible, are those due to any want of balance in other periods. This may occur in respect to the position of perigee; but it would only be appreciable in regions where the effect of the moon's distance is large, and also when the date of the missing tide curve was near to perigee. The forms of the curves on days a month earlier and later, being displaced 1½ days relatively to perigee where change is rapid, might be affected. At any other time in the anomalistic month, the error from this cause would scarcely be appreciable.

Another influence that may be unbalanced, is the declination of the Sun; especially since in the Declinational type of tide, this solar effect is so evident. The examples here under consideration are both near the solstices, when the solar element in the diurnal inequality is at its maximum. At the break in January 1919, the interval of 29 days before one of the missing days, falls practically on the solstice; and 29 days after, falls two months from the solstice.

The possibility of these sources of error can always be seen from the astronomical conditions at the time. To obtain a check upon them, the Tide Table values may be resorted to. It is to be noted that in these prediction values, all the influences affecting the tide, due to every movement of the sun and moon, are taken into account; and consequently the *relative* positions of the points of high and low water on different days, as given by their co-ordinates on the prediction curves, may be taken as correct. On the other hand, the *absolute* positions of these points, with relation to the observed points, may be considerably out of place; especially in early Tide Tables which are based on the first year or two of harmonic analysis, when the variation in the 19-year declination cycle may not yet be well determined.

A point at high or low water on a missing day, can therefore be plotted on the tide diagram by placing it in the same position relatively to the observed points that the Tide Tables indicate. The relative and absolute positions of these points are shown in the Plates attached; one of these giving the sets of points on an enlarged scale.

The Tide Table values may also be utilized if a check comparison is thought necessary, where the pair of curves between which the interpolation is made are too far apart, or in dealing with the half-tides of

less amplitude. By using some judgment in this matter, the system of computation need only be used for certain selected tides; which will save labour.

Summary.—The general procedure in making the interpolation for each missing day may be thus summarized:

Trace the tide curves from the record obtained with the registering tide guage, 29 days before and 29 days after the missing day; the two curves to be placed on the same sheet, graduated for time and height. Draw an interpolated curve precisely midway between these in respect to both time and height.

Before accepting this interpolated curve as correct for the missing day, the points of high water and low water are to be checked. If the diurnal inequality is large at the date dealt with, compute the time and height of the Higher high water and the Lower low water by the system described; basing the computation on readings from the recorded tide curves. The points thus computed, to be plotted in position; and the interpolated curve to be modified to pass through them, tangentially to the horizontal. This procedure will show whether or not it was correct to assume that the interpolated curve was midway between the original pair, especially in places where the pair are somewhat widely separated.

When it is suspected that any element in the tide still remains unbalanced, because of the astronomical conditions at the time, the Tide Table values at high and low water may be plotted; and the similar points on the interpolated curve can be compared with these, to see that they have the same relative positions with respect to the high and low water points on the recorded curves.

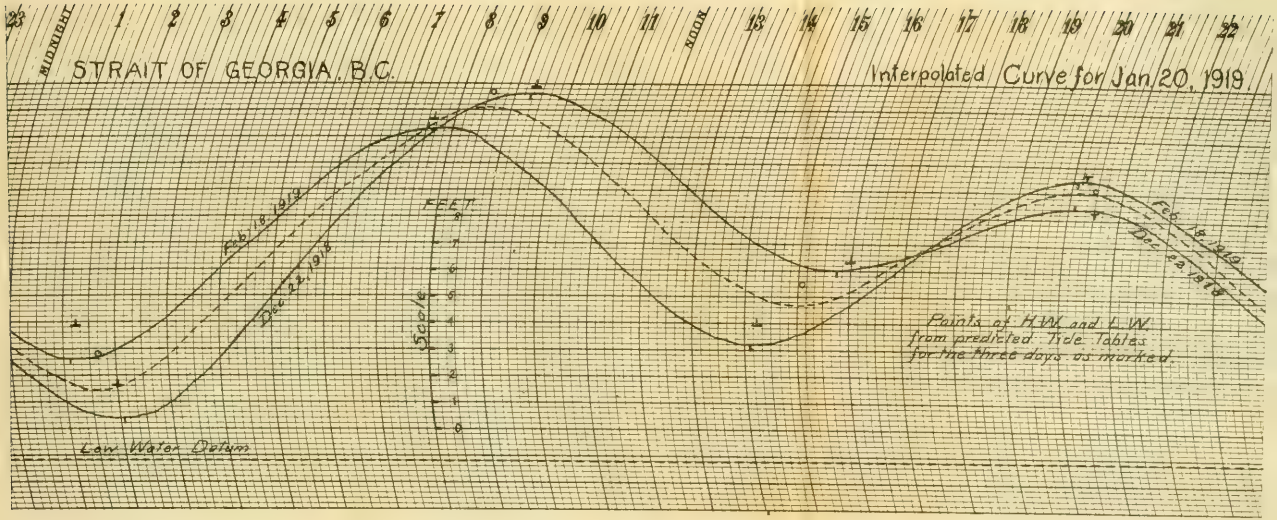
When these modifications and comparisons are made, and found satisfactory, the interpolated curve can be accepted as finally correct. The method here described, should apply equally well to other types of tide; and it should often enable a large part of a year of valuable tidal record to be saved, when interruptions occur, and utilized for harmonic analysis.

Supplementary Note.—It has been assumed that the interruption requiring interpolation occurs after Tide Tables are available from analysis of the first year or two of observation. But if the interruption occurs a few months after observations are begun at a new locality, as for example in the first winter after a good summer season, this method of interpolation is still applicable. The only disadvantage is the loss of the check for outstanding errors due to any astronomical conditions that remain unbalanced, when these are not negligeable in amount.

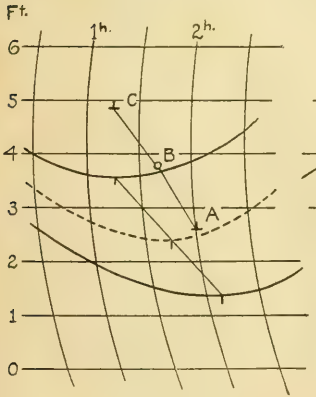
APPENDIX

Computation in the periods of the Synodic and Declinational months, taken separately. Synodic month, 29½ days; Declinational month, 27½ days. All the readings as entered are from the recorded curves.

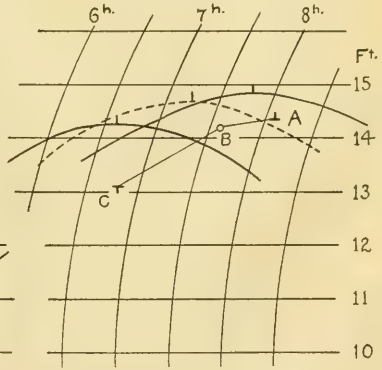
Dates in 1919 and 1920	High Water		Low Water	
	Time.	Height	Time.	Height
I.—IN THE SYNODIC MONTH.				
	H.M.	Feet	H.M.	Feet
Nov. 17.—30 days before missing day....	13:25	12.9	20:35	4.0
Nov. 18.—29 days before missing day....	14:10	12.8	21:15	3.6
Jan. 15.—29 days after missing day	12:00	12.1	19:55	2.9
Jan. 16.—30 days after missing day.....	12:55	11.7	20:40	2.5
Mean Synodic values.....	13:07	12.4	20:36	3.2
II.—IN THE DECLINATIONAL MONTH.				
	H.M.	Feet	H.M.	Feet
Nov. 19.—28 days before missing day....	14:35	12.4	21:45	2.1
Nov. 20.—27 days before missing day....	15:05	11.5	22:15	1.2
Jan. 13.—27 days after missing day.....	10:50	12.8	18:20	3.6
Jan. 14.—28 days after missing day.....	11:25	12.4	19:15	3.4
Mean Declinational values	12:59	12.3	20:24	2.6
Mean of the two sets; giving Dec. 17.....	13:03	12.3	20:30	2.9
COMPUTATION BY THE STANDARD SYSTEM.				
	H.M.	Feet	H.M.	Feet
Nov. 18.—29 days before missing day....	14:10	12.8	21:15	3.6
Nov. 19.—28 days before missing day....	14:35	12.4	21:45	2.1
Values for 28½ days before.....	14:22	12.6	21:30	2.8
Jan. 14.—28 days after missing day.....	11:25	12.4	19:15	3.4
Jan. 15.—29 days after missing day.....	12:00	12.1	19:55	2.9
Values for 28½ days after.....	11:43	12.2	19:35	3.2
Mean of the two; giving Dec. 17.....	13:02	12.4	20:33	3.0


MIDNIGHT
1 2 3 4 5 6 7 8 9 10 11
NOON
13 14 15 16 17 18 19 20 21 22
STRAIT OF GEORGIA, B.C.
Interpolated Curve for Jan. 20, 1919.
FEET
Scale
Feb. 18, 1919
Feb. 22, 1919
Feb. 18, 1919.
Dec. 24, 1918
Points of H.W. and L.W. from predicted Tide Tables for the three days as marked.
Low Water Datum

Lower L. W. on Interpolation for Jan. 20.

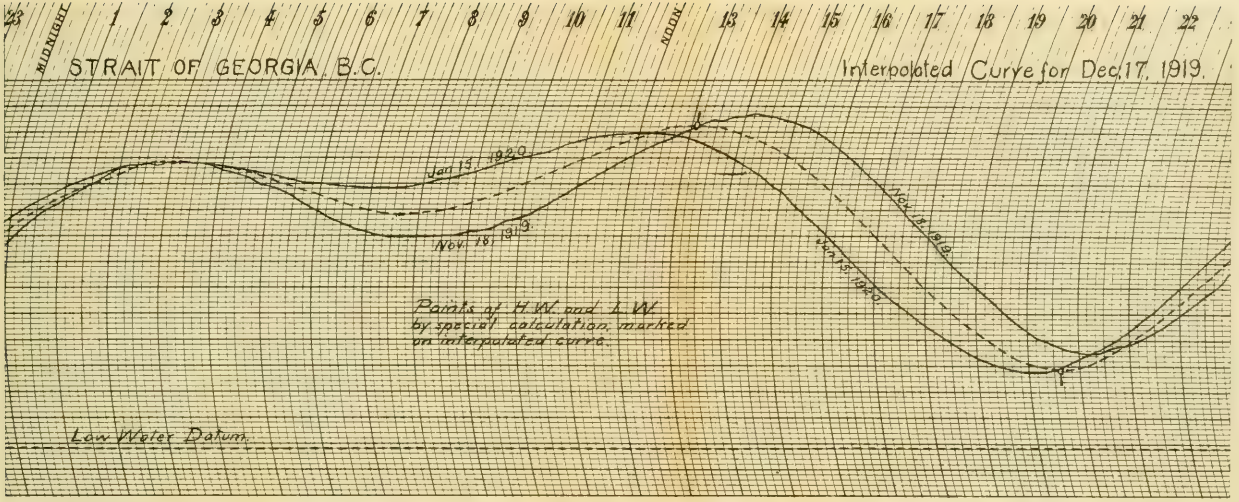


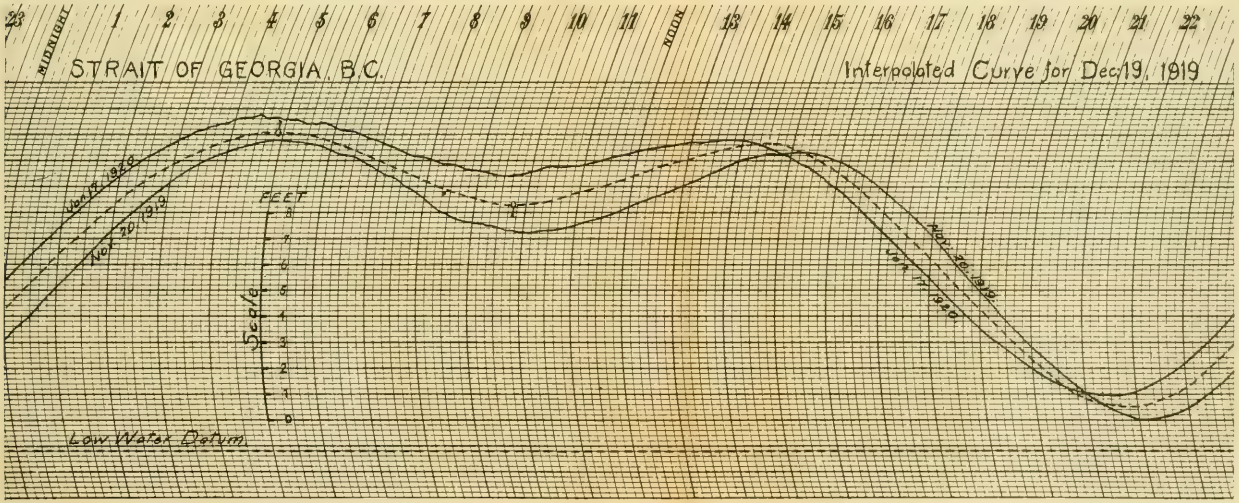
Higher H.W. on Interpolation for Jan. 18.



Enlarged diagrams to show Relation of the Recorded and Interpolated curves to the predicted values of H.W. and L.W. in the Tide Tables.

A. B. C. — Tide table values in December, January and February respectively.


23 MIDNIGHT 1 2 3 4 5 6 7 8 9 10 11 NOON 13 14 15 16 17 18 19 20 21 22
STRAIT OF GEORGIA, B.C.
Interpolated Curve for Dec. 17, 1919.
Jan 15 1920
Nov 18 1919
Nov 19 1919
Jan 15 1920
Points of H.W. and L.W. by special calculation, marked on interpolated curve.
Low Water Datum.


23 MIDNIGHT 1 2 3 4 5 6 7 8 9 10 11 NOON 13 14 15 16 17 18 19 20 21 22
STRAIT OF GEORGIA, B.C.
Interpolated Curve for Dec. 19, 1919.
Jan 19 1920
Nov 20 1919
FEET
Scale
Nov 20 1919
Jan 19 1920
Low Water Datum.

The close agreement of the standard system with the more elaborate method, in which the two types of month are computed separately, will be noted.

SIMPLIFIED ARRANGEMENT.—This further example of the standard method, shows the set of four days averaged together directly, for simplification; as the result is the same, arithmetically, as when averaged in two pairs separately.

Dates in 1919 and 1920	High Water		Low Water	
	Time.	Height	Time.	Height
	H.M.	Feet	H.M.	Feet
Nov. 20.—29 days before missing day....	5:00	11.9	10:05	8.3
Nov. 21.—28 days before missing day....	5:35	12.4	10:45	8.5
Jan. 16.—28 days after missing day.....	4:15	11.8	8:40	10.2
Jan. 17.—29 days after missing day.....	4:40	12.8	9:35	10.5
Average of the four; giving Dec. 19.....	4:52	12.2	9:46	9.4

THE MEASUREMENT OF SMALL CAPACITIES

By E. S. Bieler, M.Sc.

Presented by Dr. A. S. Eve, C.B.E., F.R.S., F.R.S.C.
(Read May Meeting, 1920).

In connection with some tests on high-tension porcelain insulators of the suspension type, it was found necessary to measure the capacity of one or more of these in series. Special precautions had to be taken in the measurement, as the total capacity usually amounted to less than 25 micro-microfarads (22.5 cm.).

Several methods were considered. Commutator and tuning-fork methods have become obsolete since the advent of generators of fairly high-frequency alternating-current of pure sine-wave form. The charge-sharing method used by Mr. Norman Campbell[1] for ionization measurements, although well adapted for measuring the capacity of electrometers, is not so convenient in the case of other small capacities.

It was soon found that some bridge method must be adopted. The question of bridge measurements with alternating currents has been very ably treated by Mr. G. A. Campbell[2] in an article entitled "Shielded Balance," but the arrangement of apparatus he describes, although well suited for institutions where measurements of capacity and inductance are continually being made, necessitates too great an outlay to be worth installing for a single research.

Two variations of a bridge method were used. It was considered that the description of these methods would be of general interest. In the second method, in particular, the use of a guard-ring condenser with alternating current by double balance should invite special attention.

I.—Comparison with a Muirhead Air Condenser

The two end terminals A and B (Fig. 1) of a Kelvin-Varley Slide Potentiometer were connected by means of a twin cable with an earthed sheath to a Vreeland Oscillator giving a pure sine-wave of current at about 12 volts and any frequency from 400 to 1,500.

The insulators whose capacity was required, were suspended from the ceiling by a rope, about 1 ft. from the Slide. The top of the string

[1] Norman Campbell, "A Note on a Method of Determining Capacities in Measurements of Ionization", Phil. Mag., 1911, Vol. 21, p. 42.

[2] G. A. Campbell, Electrical World, 1904, Vol. 43, pp. 633, 647.

was earthed and connected to the third terminal D of the Slide through a Brown telephone of 5,000 ohms resistance. The bottom could be connected to either of the other terminals A and B of the Slide.

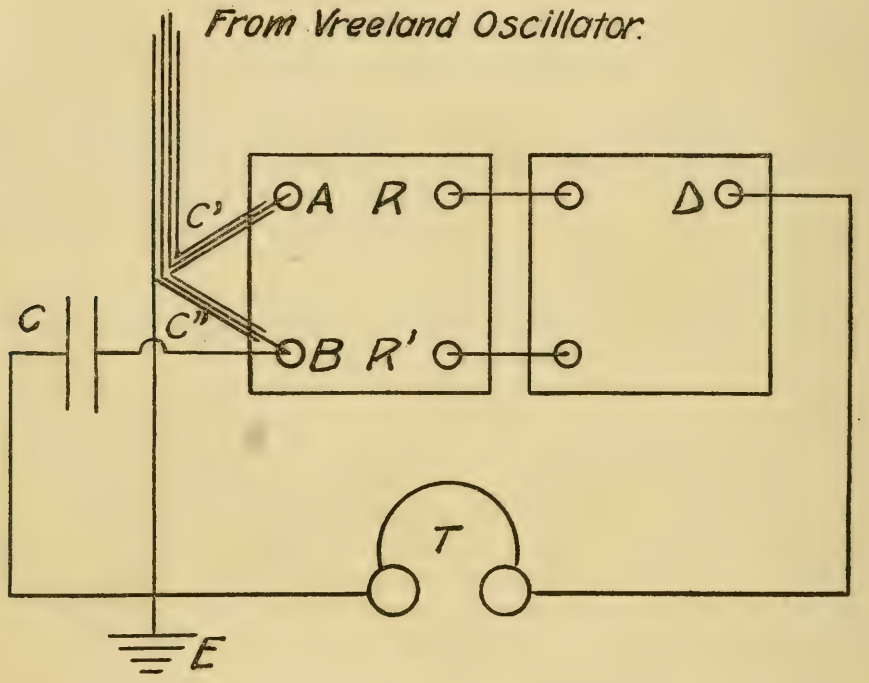


Fig. 1

Let R, R', be the resistances included in arms AD, DB, respectively.

Let C be the capacity to be measured.

Let C' be the capacity between the sheath and the lead to A.

Let C'' be the capacity between the sheath and the lead to B.

If R_1, R_1' are the values of R, R' when balance is obtained with C connected up as in the figure, we have,

$$(C+C'')/C' = R_1/R_1'. \qquad (1)$$

If $R_2 = R_2'$ are the values of R, R' when balance is obtained with C connected up as in the figure, we have,

$$(C+C')/C'' = R'_2/R_2. \qquad (2)$$

After C', C'' have been determined as indicated below, equations (1) and (2) give us two values of C, the mean of which may be taken.

By deducting the lead capacity obtained in the usual way, the net capacity of the insulators can be determined.

The value of the capacities C' and C'' can be obtained as follows.

Connect up as in the figure, leaving out C. If R_3, R_3' are the values of R, R′, when balance is obtained, we have,

$$C'/C'' = R_3'/R_3. \qquad (3)$$

Now, in place of C, put in a known capacity C_1. If R_4, R_4' and R_5, R'_5 are the values of R, R′ when balance is obtained with C_1 connected to B and A respectively, we have,

$$(C_1+C'')/C' = R_4/R_4', \qquad (4)$$

and,

$$(C_1+C')/C'' = R'_5/R_5. \qquad (5)$$

Equations (3), (4), and (5) give two determinations of C′ and C″, the mean of which may be taken.

Taking as standard a Muirhead concentric cylinder air condenser, whose capacity, as found by measurement, was 0.00520 mfd., the following capacities were found for one, two, and three ordinary ten inch suspension-type insulators.

TABLE I.

Specimen	Capacity, Micro-mfd.	Lead Capacity, Micro-mfd.	Net Capacity, Micro-mfd.	Cm.
A	29.6	7.5	22.1	19.9
B	33.4	7.5	25.9	23.3
Mean for one Insulator.			24.0	21.6
A and B Series	18.4	7.5	10.9	9.8
C and D Series	20.3	7.5	12.8	11.5
Mean for two Insulators			11.8	10.7
B, C and D Series	16.5	7.5	9.0	8.1

II.—COMPARISON WITH A GUARD-RING CONDENSER

The Muirhead condenser had over one hundred times the capacity of a single insulator; to obtain more accurate results, it was found necessary to compare the insulator capacities with a capacity of approximately the same value, and a special guard-ring condenser had to be built. In addition, the capacity between the leads and the sheath was not strictly constant, so that this capacity had to be removed to a part of the bridge where a small variation in it would have no appreciable effect.

The arrangement of apparatus was therefore changed to that given in Fig. 2.

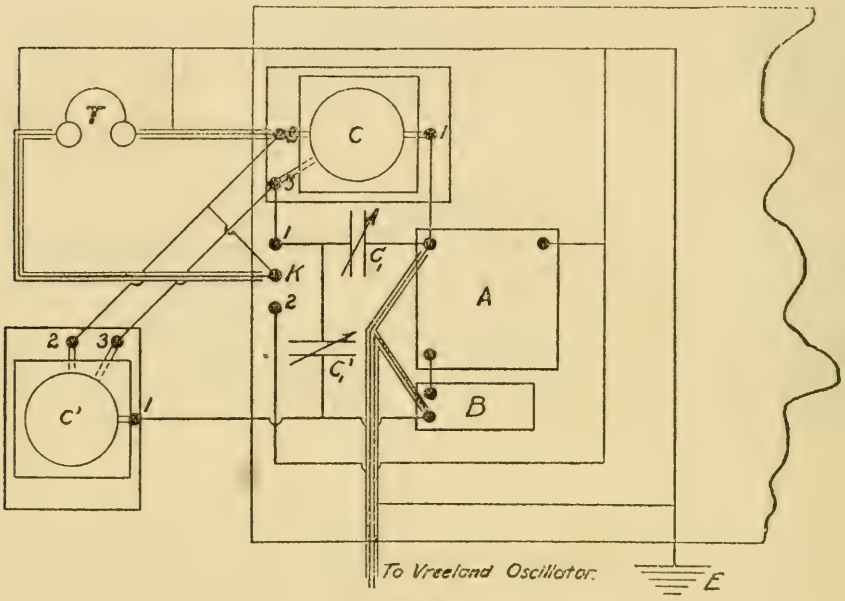


Fig. 2

A is the low resistance side of a Kelvin-Varley Slide Potentiometer consisting of 100 twenty ohm coils.

B is a plug resistance-box, from which a small resistance is taken to allow of adjustment between the twenty ohm steps of the Slide.

C and C′ are two guard-ring condensers made up of glass plates, coated with tinfoil. The upper plate of each is connected to terminal (1) In the tinfoil of the lower plate is cut a circular part connected to terminal (2). The ring around it is connected to terminal (3). The two plates are kept apart by means of small distance-pieces of glass or other material, whose thickness is accurately measured. C rests on a table; C′ is suspended from the ceiling by a rope, and after calibration of the bridge, it is replaced by the capacity to be measured.

C_1 and C_1' are two adjustable parallel plate condensers, of which C_1' is provided with a micrometer screw for close adjustment.

K is a two-way key, and T a 5,000 ohm Baldwin telephone.

The junctions of a resistance arm and a capacity arm are connected to a Vreeland Oscillator.

The leads from the Vreeland Oscillator and the telephone leads are shielded by earthed metallic sheaths. The movable contact of the Slide

is also earthed. Thus, the junction of the condensers is effectually earthed when balance is obtained, but the capacities between the leads and the sheath are now in parallel with the resistance arms of the bridge. The resistance arms are of such low impedance that these capacities introduce only a negligible phase shift.

The theory of the method is better understood by reference to Fig. 3.

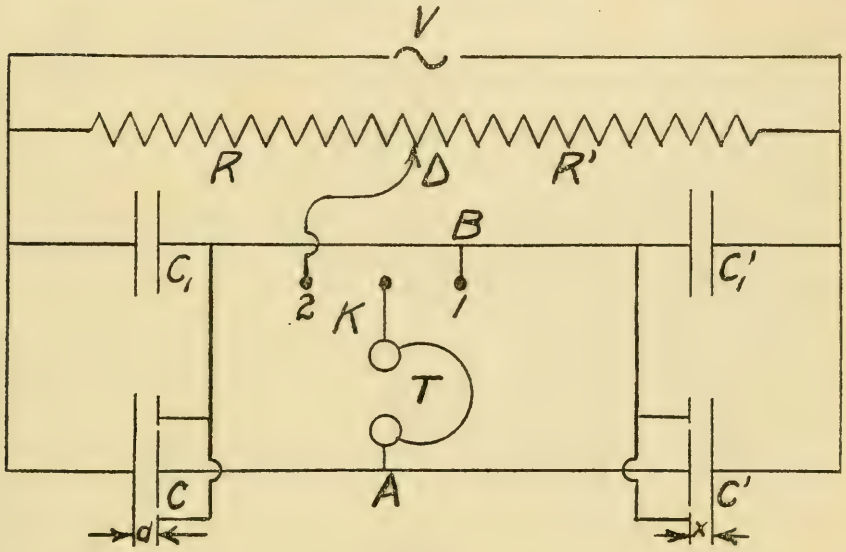


Fig. 3

Let C, C′, be the capacities of two guard-ring condensers.

Let A be th area of their guarded plates,

d, x, be the distances between their plates,

a, b, be the capacity of the leads to them,

C_1, C_1', be the capacities of their guard-rings together with small adjustable condensers in parallel with them.

K is a two-way key, T a telephone, and V a source of alternating current of frequency f, or $p/2\pi$.

With the key in position (1), condenser C'_1 is first adjusted until there is silence in the telephone, and then, we have,

$$(C+a)/C_1=(C'+b)/C_1'$$

Also the voltages at A and B are in phase and equal, so that the condensers act as true guard-ring condensers, and we may write,

$$C=A/4\pi d,$$

$$C'=A/4\pi x.$$

With the key in position (2), the movable contact D is then adjusted until silence is again obtained.

If we assume the inductance of the slide to be evenly distributed, we may write the impedances of the two parts as R $(1+iq)$, $R_1(1+iq)$, where q is some constant.

Also, the impedances of the capacity arms are $1/ip(C+a)$, $1/ip(C'+b)$

When balance is obtained, we have,

$$\frac{R\,(1+iq)}{R'\,(1+iq)}=\frac{ip\,(C'+b)}{ip\,(C+a)}$$

that is, $R/R'=(C'+b)/(C+a)$.

If the lead capacity a is negligible, this reduces to

$$\frac{R}{R'}=\frac{A/4\pi x+b}{A/4\pi d}$$

or $R/R'=d/x+4\pi db/A$.

Thus, there is a straight line relation between R/R' and $1/x$. The $1/x$ intercept is $-4\,b/A$, a quantity independent of d. Thus the curves connecting R/R' and $1/x$ for various values of d should cut the axis of $1/x$ at the same point.

Further, if we call this intercept $-I$, we can easily calculate the lead capacity from the relation $b=AI/4\pi$. The value of b obtained should be independent of A.

Comparison of the graphs of Figs. 4a and 4b, obtained with plates of different areas A shows that these conditions are very nearly fulfilled.

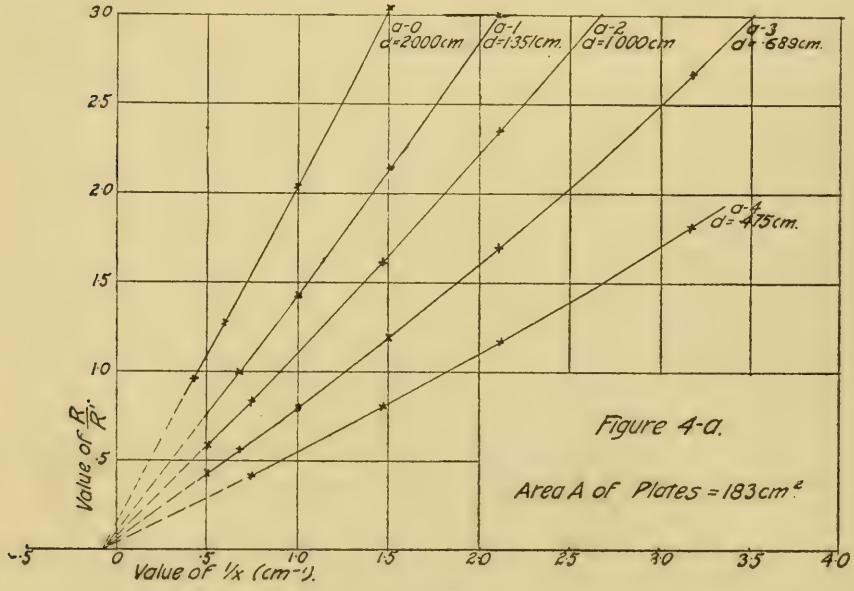


Fig. 4a

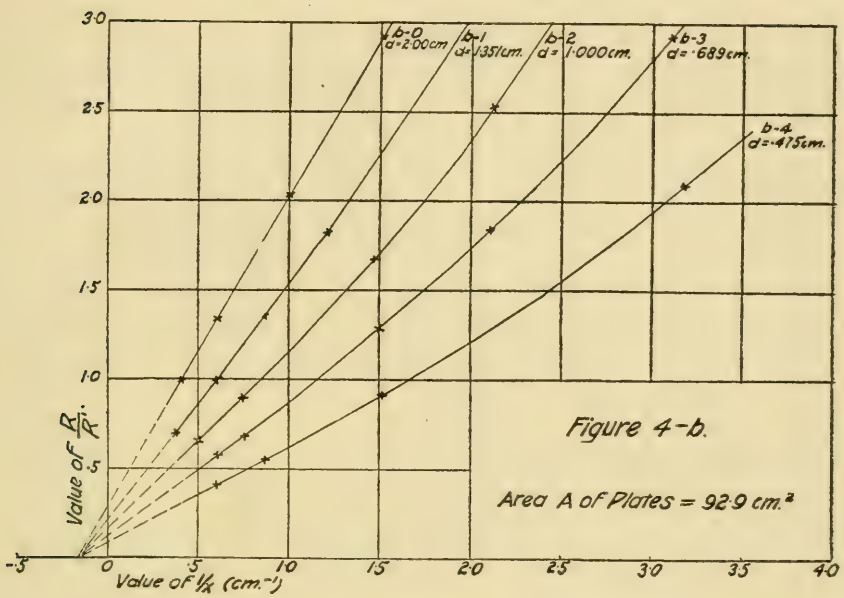


Fig. 4b
Relation between the Value of R/R' and the Reciprocal of the Distance x between the Plates of Guard-ring Condenser C'.
d = Distance between the Plates of Guard-ring Condenser C.
Frequency f of supply = 1020.

The values of b obtained from Fig. 4a and 4b are 1.18 cm. and 1.16 cm. respectively. The leads are, of course, not the same as those of Method I, for which the correction is much larger.

When a curve connecting R/R′ and $1/x$ has been obtained, the capacity to be measured is substituted for the guard-ring condenser C′, and the same adjustments made. From the new value of R/R′, the corresponding value of $1/x$ may be found from the curve, and the capacity calculated by means of the formula $C' = A/4\pi x$.

The results of measurements on various types of insulators are given in Table II.

TABLE II.

ORDINARY SUSPENSION TYPE INSULATOR

Specimen	d	Curve	R	R′	Mean R′	R/R′	$1/x$	Capacity
A	.476	a-4	45	55.3 55.5	55.4	.812	1.495	21.78cm.
B	.476	a-4	45	55.4 55.4	55.4	.812	1.495	21.78cm.
A	.689	a-3	54	46.75 46.80	46.78	1.115	1.455	21.19cm.

TABLE II—*Continued.*

Specimen	*d*	Curve	R	R′	Mean R′	R/R′	1/*x*	Capacity
B	.689	a-3	54	46.60 46.40	46.50	1.161	1.460	21.24cm.
Mean for one insulator.								21.50cm.
2 in series	1.000	a-2	44	56.3		.782	.700	10.20cm.
2 in series	1.351	a-1	52	50.9		1.021	.700	10.20cm.
Mean for two insulators in series								10.20cm.
3 in series	1.351	a-1	41	59.2 58.6	58.9	.696	.445	6.48cm.
3 in series	2.000	a-0	50	50.8 51.8	51.3	.975	.438	6.38cm.
Mean for three insulators in series								6.43cm.
4 in series	1.351	a-1	35	67.3 67.7	67.5	.518	.315	4.59cm.
4 in series	2.000	a-0	41	59.3 58.4	58.85	.697	.285	4.15cm.
Mean for four insulators in series								4.37cm.

JEFFREY-DEWITT SUSPENSION TYPE INSULATOR

Specimen	*d*	Curve	R	R′	Mean R′	R/R′	1/*x*	Capacity
2-A	1.000	a-2	54	46.1 45.7	45.9	1.176	1.020	7.55cm.
2-B	1.000	a-2	55	45.7 45.5	45.6	1.206	1.050	7.77cm.
Mean for one insulator								7.66cm.

HEWLETT SUSPENSION TYPE INSULATORS

Specimen	*d*	Curve	R	R′	Mean R′	R/R′	1/*x*	Capacity
3-A	2.000	a-0	68	32.8 32.8	32.8	2.072	.690	5.11cm.
3-B	2.000	a-0	69	32.4 32.4	32.4	2.128	.700	5.18cm.
Mean for one insulator								5.14cm.

Comparison between Tables I. and II. shows that the second method gives much the more satisfactory results. It is applicable to the measurement of other small capacities, such as that of electrometers.

It must be remembered that, in Method II., there is some uncertainty about the lead correction. If the leads to the insulators and to the guard-

ring condenser could be made exactly the same in length and position, no further correction would be needed. This condition could, however, never be secured completely, and the correction applied is perhaps a little too large in the case of two or more insulators in series. The error from this source is small, however, since the lead correction is never much more than 20 per cent. of the whole capacity, and Method I. gives exactly the same lead capacity for two or three insulators in series as it does for one.

In concluding, the writer wishes to thank Dr. A. S. Eve for his kindly interest in the work and Dr. L. V. King for many valuable suggestions.

McGill University, July, 1920.

SUMMARY

The Measurement of Small Capacities of the order of 10 micro-microfarads is studied with special reference to that of High-Tension Porcelain Suspension Type Insulators.

Two variations of an Alternating-Current Bridge method are given, namely,

I. Comparison with a Muirhead Air Condenser.

II. Comparison with a Guard-Ring Condenser. In this case, the conditions necessary for the use of a Guard-Ring Condenser are obtained by means of Double Balance.

Two tables are given of the values of the capacities of various types of these insulators singly and in series.

THE ADIABATIC CONDENSATION OF ETHER VAPOUR

By A. L. Clark, Ph.D., F.R.S.C.

Read May Meeting, 1920.

It is a well known fact that water vapour under certain conditions condenses when expanded adiabatically. If the water vapour in the air is approximately near the saturation point, an adiabatic expansion will bring about condensation, which is greatly facilitated by the presence of nuclei in the air. No doubt almost all cloud formation is due to adiabatic condensation of moisture laden air. Conversely the adiabatic compression of a fog bearing body of air will bring about evaporation of the cloud if the compression is sufficiently great. We find evidence of both phenomena in the well known alto-wave cloud formation, or in the common cirrocumuli of "mackerel sky." The visible portions are the crests of waves where the expansion accompanying increase in altitude has brought about cloudy condensation, while the blank spaces are the troughs of the waves where compression accompanying rapid descent has evaporated the cloud or has prevented its formation.

The condensation mentioned is, of course, independent of the presence of air and takes place equally well in a closed tube where only water and water vapour are present. The same is true of the vapours of other liquids, indeed nearly all, in fact of all except a very few, notably ethyl ether whose saturated vapour has a positive specific heat at ordinary temperature. That the vapour of water should condense upon adiabatic

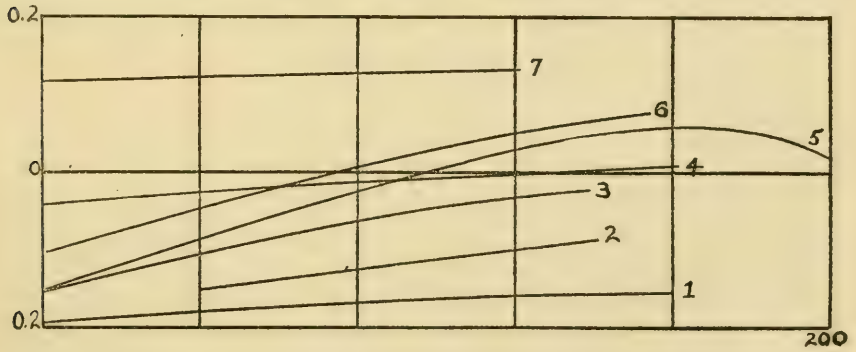


Fig. 1.

1. Water. 2. Carbon Bisulphide. 3. Acetone. 4. Carbon Tetrachloride. 5. Benzine. 6. Chloroform. 7. Ethyl Ether.

expansion was announced simultaneously by Clausius[1] and Rankine[2] and was shown later experimentally by Hirn[3].

This phenomenon was shown by Clausius to be a necessary consequence of the fact that the specific heat of water vapour is negative. It is shown in the larger treatises on Thermodynamics that where the specific heat of a saturated vapour is negative, adiabatic expansion causes condensation if there is not too much liquid present, while, if the specific heat is positive, expansion always causes evaporation of the liquid. That the specific heats of the vapours of many common liquids are negative is shown by figure 1, which was plotted from the data given by Duhem[4]. While there seems to be considerable diversity in the variations in the specific heat, Duhem has shown that there are only two classes of substances, those for which the specific heat of the saturated vapour is always negative and those for which the specific heat is negative for very low and very high temperatures becoming zero for two intermediate temperatures between which it is positive. Raveau[5] showed that the specific heat of a saturated vapour becomes negatively infinite at the critical temperature, while that of the liquid becomes positively infinite at the same temperture. So, it would appear that while the specific heat of ether vapour is positive throughout the region in which it has been studied, it must become negative as the temperature is raised to a point near the critical temperature. If this is so, adiabatic expansion should produce condensation of the vapour as it does with water and most other liquids[6].

This phenomenon of condensation has been observed repeatedly with a very simple apparatus. This apparatus resembles the classical apparatus of Andrews and was built for lecture demonstration of the phenomena exhibited by a liquid and its vapour near the critical point. A thick walled glass tube of a few mm. bore and about 30 cm. long was

[1]Clausius Pogg. Ann. LXXIX, 368, and 500, 1850.

[2]Rankine, Trans. Roy. Soc. Edin. XX, I, 157, 1850.

[3]Hirn, Bull. de la Soc. Industrielle de Mulhouse No. 183.

[4]Duhem, Traite Elementaire de Mecanique Chimique, vol. II, p. 213.

[5]Raveau, Jour. de Physique 3. I, 461, 1892.

[6]Mathias (Annales de la Faculté des Sciences de Toulouse T, 10, 1896) has shown that sulphurous acid behaves according to theory. He measured the specific heats of both liquid and vapour from 0° to 155° C, or just below the critical temperature and found the specific heat of the liquid is always positive and increases slowly until at about 130° when it grows larger rapidly and becomes very large. The specific heat of the vapour is negative at 0°, increases to zero at about 98°, remains positive for a short interval, reaches a second point of inversion at 116° and then changes sign becoming very large negatively at 155°. In all probability the same general trend would be observed for other liquids, though many would never be positive and have no points of inversion.

secured into a mercury chamber by a rubber packed stuffing box[7]. The chamber is connected by a steel tube to a second chamber containing oil under a screw which can be used to create pressure in the glass tube. The tube has a small amount of ethyl ether on top of the mercury. A small metal box containing coils of nichrome wire surrounds the upper part of the glass tube so that the tube and its contents may be heated to any desired temperature. Since the tube is surrounded by air as the only heating agent, the temperature is not as uniform as might be desired, but the apparatus serves very well. With this apparatus it is easy to bring the temperature to any desired point and then to change the volume

FIG. 2.

at will. Among other things it is easy to show the continuous change from liquid to vapour as exhibited by Andrews, a point of which so much was made by van der Waals.

It is easy to see the effect of adiabatic expansion by plotting the lines of constant dryness on the temperature-entropy diagram and observing how the adiabatics or isentropics cut these lines. We have the necessary data in the results of Regnault for most of the common liquids. The entropy of the vapour calculated from zero Centigrade as the starting

[7]Clark, Proc. Am. Acad. of Arts and Sciences. XLI, 371, 1906.

point is given by

$$S = c \log T/T_0 + Lx/T$$

where c is the specific heat of the liquid (taken as constant), T is the temperature at which evaporation occurs, T_0 is the initial temperature (0^0 C), L is the latent heat of vaporization, and x the dryness or fraction of the mass which is vapour. If x be taken as unity the graph of the equation $S = c \log T/T^0 + L/T$ is the boundary between saturated vapour and unsaturated vapour. If we put x equal to any proper fraction, we have in the same way a curve of constant x, or a curve of constant dryness. These curves in Fig. 2 were drawn from calculations based on the data of Regnault. The curves for water slope downward toward the right for x greater than .5 and toward the left for smaller values. The curves for ether all slope downward toward the left. The ordinates represent temperature and the abscissae, entropy from 0^0C.

Mathias[8] has shown that for a saturated vapour an adiabatic increase in volume is always accompanied by a lowering of temperature so that an adiabatic or isentropic expansion is represented by a vertical line on the diagram and the state point descends as the substance expands. The condition of the vapour, which is always in the upper part of the tube, corresponds to a point well over toward the right of the diagram, in fact it actually may be in the unsaturated portion owing to the effect of gravity which separates liquid and vapour everywhere except at the interface. So, when water vapour is expanded the state point moves down and either cuts across the condensation line or meets successively lines of increasing values of x so that condensation must result.

In the case of the adiabatic expansion of ether vapour, at least at the temperatures included in the diagram, the state point moving down cuts the lines of constant x, so that the value of x is decreasing or the vapour gets dryer, If there is liquid present, it evaporates. The data for ether given by Regnault extend only to 230° C. so that the range of phenomena interpreted though the diagram is limited. If, as stated by Raveau, the value of the specific heat becomes negative as the critical point is approached, it should be possible to get condensation with expansion, at sufficiently high temperatures. This was found to be the case and it is quite easy within a small range of temperature near the critical temperature to bring a dense cloud of vapour with a slight expansion. As the temperature is lowered it is not easy to accomplish this and as the temperature is lowered still more no cloud appears on expansion but upon compression there is evidence of condensation on the walls of the tube, though we never see the dense cloud that we do near the critical temperature.

[8]Mathias, Jour. de Physique, 4, 7, 618, 1908.

Somewhere between 120° and 194°, the specific heat becomes zero and changes sign and the temperature-entropy diagram must show the lines of constant x leaning over toward the left as the temperature is raised, probably somewhat as shown in the diagram of Fig. 3.

FIG. 3.

Strictly speaking, as was shown by Raveau, whether condensation or evaporation occurs when a saturated fluid is expanded adiabatically, depends on the algebraic sign of the expression

$$xh+(1-x)c$$

where h is the specific heat of the saturated vapour. This may be shown easily as follows. If we take the result given by Mathais already referred to viz., that the temperature falls upon adiabatic increase in volume, we may use the expression for the heat absorbed by a saturated liquid and vapour

$$dQ=Ldx\ [hx\ (1-x)]\ dT$$

where L is the heat of vaporization. For an adiabatic expansion this is zero and

$$\frac{dx}{dT}=\frac{L}{hx\ (1-x)\ c}$$

If h be positive, dx is positive, or the mixture becomes dryer when expanded. If on the other hand h be negative the expression $hx+(1-x)c$ may be negative and then dx is negative and the mixture becomes wetter upon expansion. If x is near unity, a negative value of h always means condensation with expansion, but if x is small, $hx\ (1-x)c$ may be positive even when h is negative, and then evaporation results. Thus if water vapour contains too much liquid it will not condense. This is shown also by the manner in which the isentropic cuts the lines of constant x for $x<0.5$. This is, however, not a very practical point as the condition of the vapour must be very near the state, $x=1$.

The condensation of ether vapour near the critical temperature may then be taken as a proof that the specific heat of the vapour is negative, as demanded by the investigations of Raveau.

THE SUCCESS OF REPRODUCTION IN SAGITTA ELEGANS IN THE BAY OF FUNDY AND THE GULF OF ST. LAWRENCE

By A. G. Huntsman and Margaret E. Reid,
University of Toronto.

The plankton of the Bay of Fundy is very poor in larvae of fishes. The tributary bays or basins, it is true, may contain rather large quantities of fish fry, particularly in the spring and early summer; but the bay itself seems remarkably barren. The larvae that do occur are of those fishes that have attached or demersal eggs. The larvae of fishes with pelagic or floating eggs are noticeably absent. The floating eggs themselves are common enough, although rarely very abundant. It is reasonable to conclude that the eggs fail to give rise to larvae.

What are the peculiarities of this region that distinguish it from those coastal waters in which development of these fishes is successful? The Bay of Fundy is noted for its high tides, for its strong tidal currents, and for the prevalence of fogs. We have here a chain of conditions. The shape of the bay and the nature of its connections give full play to tidal action. The resultant swift currents in flowing over shoals and through passages mix the water rather thoroughly from surface to bottom, particularly between the group of islands, known as the Western Archipelago, placed at and near the entrance to Passamaquoddy bay. The effect of the mixing is that the surface water is never able to attain a high temperature during the summer. It, therefore, remains cool, and chills the air above it, thus producing the fogs. The surface water is not only kept cool, but is also kept very salt by being constantly mixed with the colder, salter water below. We thus have a correlation between these conditions and the failure in the development of certain fishes. Whether the failure is the result of one of these conditions, or of some factor associated with them, remains to be determined.

Not only are many fishes affected in this way, but also a number of invertebrates. The medusa, *Aglantha*, the amphipod, *Parathemisto*, the schizopod, *Meganyctiphanes*, and the pteropod, *Clione*, may be mentioned as species that are to be found in the bay as adults, but that fail to reproduce successfully there, although doing so elsewhere along our coast. It has been stated (Huntsman, 1919, p. 468) that the young of the Chaetognath, *Sagitta elegans*, are to be found generally along our coast in the summer, but are noticeably few or lacking in the Bay of Fundy, although the adults are usually to be found there in large numbers.

We have undertaken to investigate this matter more thoroughly, in the belief that it has a very general import, and that it vitally affects the distribution and abundance of many of our commercial fishes. We purpose using *Sagitta elegans* as a type, inasmuch as it is of very general occurrence, and is of such sizes as to be obtained easily in plankton hauls in all stages of its life history.

We are indebted in this, as in many other instances, to Professor A. Willey of McGill University, for much advice and assistance, particularly in the matter of the discovery and identification of the eggs of *Sagitta elegans*.

VERTICAL DISTRIBUTION.

The adults are usually confined to the deeper levels of the water. This is shown by the results of hauls made in deep water some distance from land, as at "Prince" stations nos. 2 and 3 (Huntsman, 1919, p. 463). Vertical hauls from near the bottom yielded a considerable number of individuals, whereas tows made near or a slight distance below the surface (down to 20 metres) gave none, or only one small specimen. In channels and near shoals where the strong tidal currents effect a considerable vertical movement of the water, all stratification is lost. Not only do the tows made at any depth almost invariably yield *Sagittae*, as at "Prince" station 1 (Huntsman, 1919, p. 463), but also it is a customary experience to see the animals darting to and fro near the surface of the water in the channel (Quoddy river) where this station is situated.

We may quote from a previous account (Huntsman, 1919, p. 465) based upon conditions not only in the Bay of Fundy but in our Atlantic waters generally. "*Sagitta elegans* is confined to water of comparatively low salinity. It is affected by light, coming nearer the surface at night. It is affected by temperature, keeping to the colder water. The young behave differently from the adults, living in the lighter, warmer surface water. With increasing age it becomes gradually restricted to the darker, colder water, which is deeper."

The waters of the Bay of Fundy on the whole exhibit little stratification, the mixing action of the strong, tidal currents resulting in a comparatively uniform condition from surface to bottom. This tends to eliminate the factors of temperature and salinity in the vertical distribution. It would seem that light remains as the dominating factor.

The following records show the vertical distribution for the latter part of the summer of 1916 at several points in the Bay of Fundy. Station No. 3 is between Grand Manan island and Nova Scotia; station no. 5 between Campobello island and the Wolves; and station no. 23

between St. John, N.B., and Digby, N.S. The hauls were taken vertically with a metre plankton net of no. 0 bolting cloth, closed before being brought to the surface.

"Prince" station no. 3, August 25, 1916.

Depth of haul (m.)	0–25	25–50	50–75	75–125	125–175
Length of *Sagittae* (mm.)	13–19	11–18	17–30	18– 31	12– 25
Number	5	8	15	41	4

"Prince" station no. 3, October 4, 1916.

Depth of haul (m.)	0–25	25–50	50–75	75–100	100–150	150–172
Length of *Sagittae* (mm.)		14–19	18–26	19– 33	24– 37	22– 34
Number	0	5	5	33	232	50

"Prince" station no. 5, August 16, 1916.

Depth of haul (m.)	0–30 (0-25)	30–60 (25-50)	60–90 (50-75)	90–120 (75-100)	*Note:* Wire oblique. Figures represent amount of wire out. Depths were less, perhaps as in brackets.
Lengthof *Sagittae* (mm.)	20	17–27	16–30	18–29	
Number	1	22	44	8	

"Prince" station no. 5, September 18, 1916.

Depth of haul (m.)	0–25	25–50	50–75	75–100
Length of *Sagittae* (mm.)		15	22–29	20– 33
Number	0	1	8	19

"Prince" station no. 23, September 22, 1916.

Depth of haul (m.)	0–25	25–50	50–75	75–96
Length of *Sagittae* (mm.)		16–19	18–26	16–28
Number	0	2	12	55

It is evident from these data that most of the *Sagittae* are below 75 metres depth, and only the smaller individuals are at all near the surface. There are distinct differences between the distributions for the latter part of August and those for the latter part of September and the beginning of October. The *Sagittae*, chiefly the smaller ones, were nearer

the surface in August than in the other two months. The data for temperature and salinity at the various depths at these stations on these occasions as given by Vachon (1918, pp. 309 and 311) afford no ground for considering them as factors responsible for the differences in distribution. The time of the day in every case was between noon and mid-afternoon. This does not, however, exclude variation in light from being the factor. In August of that year much fog prevailed in the Bay. The Monthly Record of Meteorological Observations for August 1916 records for St. John, N.B., only two days, (15th and 20th), in the latter part of the month as free from fog or rain, and haze and fog were experienced when the hauls were made. On the other hand in September, as given in the Monthly Record for that month, St. John experienced 13 days without either rain or fog, and clear weather prevailed when the hauls were made in that month. Likewise during the first week in October the weather was clear. We may, therefore, conclude that the *Sagittae* are driven to a lower level during clear weather than during foggy or dull weather.

At "Prince" station no. 5 hauls have been made monthly with few exceptions from May, 1916, up to the present, (December, 1920). For the first two years three hauls were taken each time, one from the bottom to the surface, a tow at a depth of about 20 metres, and another taken just below the surface. In the mild winter of 1916-1917, *Sagittae* were taken in the surface haul only in January and February. During the severe winter of 1917-1918, they were taken thus in November, December, and March, the ice preventing the hauls being made in January and February. The winter movement toward the surface might be considered as due either to the lessened light or to the lowered temperature. The evidence favours the latter interpretation. The middle of the period when the *Sagittae* are nearest the surface is about the end of January. This is the time of greatest cold, and much later than the time of least light (December 21). Conversely the *Sagittae* are deepest during a period of which the mid-point is in August, approximately the height of summer in the water.

Horizontal Distribution.

Although the adult *Sagittae* are restricted to the deeper waters of the bay, yet as the bay is nearly everywhere comparatively deep, the area occupied by the adults is very extensive, and the total number of individuals, even when not numerous at any one place, is enormous, owing to their being quite uniformly distributed. During the summer months they are comparatively rare in the tributary bays and estuaries, doubtless owing to the shallowness of these waters. However, when

they come near the surface in the cold part of the year, they are then to be found commonly, and even in large numbers, far up the estuaries.

SEASON OF MATURITY OF EGGS.

In order to determine the season of maturity of the eggs, an examination was made of the condition of the ovaries in adult *Sagittae* taken in approximately monthly hauls from July of 1916 to August of 1917 at "Prince" station no. 1, where *Sagittae* usually occur in fairly large numbers, and of a haul in September of 1917 at "Prince" station no. 5. Where large numbers were present in the hauls only 10 were examined. The recorded diameter of the eggs in each individual is the average of seven measurements, only the largest cells being taken. The average

TABLE I.

"Prince" stations nos. 1 and 5.

Date	Depth of haul (m.)	Number	Length in mm.	Aver. diam. of eggs in mm.	Diam. of largest eggs. in mm.
1916 July 10	15–18 T	10	26–31	0.203	0.315
Nov. 6	30– 0 V 0– 2 T	3 1	22.5–30 32	0.060 0.045	0.090 0.045
Dec. 4	30– 0 V	10	21–33.5	0.056	0.076
Dec. 28	0– 2 T	10	26.5–33.5	0.060	0.082
1917 Feb. 5	30– 0 V	10	30.5–36	0.080	0.099
Mar. 30	18–23 T	10	33–39.5	0.135	0.310
May 3	0– 2 T	6	23–34	0.265	0.374
May 26	10–12 T	10	25–37.5	0.233	0.398
June 16	0– 2 T	10	24–37	0.283	0.446
July 5	0– 2 T	10	28–38	0.276	0.417
Aug. 1	18–23 T	10	27–33	0.315	0.372
Sept. 4	90– 0 V	10	21.5–31	0.156	0.357

* After the depth the letter T indicates that a tow was made, and V that the net was hauled vertically.

diameter of the eggs for any month is the average of the diameters found for the ten individuals.

The table above gives the date, the kind of haul, the number of *Sagittae* taken, the lengths of those examined (which may be regarded as typical of its entire number, as no special size was chosen), the average diameter of the eggs, and the diameters of the largest eggs.

A consideration of the facts given in this table leads to the conclusion that the spawning season is a long one, extending from the end of March or the beginning of April to September at least. September 4 would seem to be near the end of the season, as at that time a smaller proportion of the individuals contained large eggs than previously.

The diameters given cannot be taken as an accurate measure of the size of the eggs, as the eggs are compressed and distorted into unspherical shapes in the ovary, and for convenience the largest diameter was always measured. Hence the actual diameter of the free egg would probably be somewhat less.

IDENTIFICATION OF THE EGGS IN THE PLANKTON.

A first examination of material from the Bay of Fundy for the eggs of *Sagittae* was fruitless, so an examination was made of material from "Prince" station no. 30 in the Gulf of St. Lawrence, off Cheticamp, Cape Breton island, where the young are known to be abundant during late spring. Weekly hauls from May 23, 1917, to July 11 of the same year were examined, and eggs were found which appeared to be those of *Sagitta*. The first ones recognized contained embryos coiled twice within the membrane, with the head slightly broader than the body. One was removed from the membrane and examined beneath the microscope, and the characteristic small black eyes of *Sagitta* were plainly discernible. They were also occasionally recognizable in the embryo within the egg. An examination of the earlier stages of the same eggs found in the hauls showed that the gastrula displayed the tripartite appearance due to the early development of gonads, which is typical of the eggs of *Sagitta*.

The diameter of the eggs—roughly about one-third of a millimeter—corresponded with the size expected from measurements of eggs within the ovary, and the length of the final embryo was approximately the same as that of the smallest *Sagittae* found. Hence it was concluded that the eggs must be those of *S. elegans*, the only Chaetognath occurring in that place.

At station no. 30 (see Table II) eggs were present in large numbers in May, and probably also in April, but disappeared in the middle of June. Three arbitrary stages in the development of the eggs were chosen, and

Seasonal occurrence of the eggs in the plankton, and the proportions of the various developmental stages throughout the season.

TABLE II.

"Prince" station no. 30.

Date	Depth of haul (m.)	* Net number	Eggs in percentages				Sagittae	
			No.	Stage 1	Stage 2	Stage 3	No.	Length (mm.)
1917								
May 23	ca. 7 T	5	116	38	28	34		
	100–0 V	0					20	10–27
May 31	0–2 T	20	32	16	47	37	6	2.5–4
	ca. 5 T	20	33	27	27	46	2	2.5
	ca. 7 T	5	84	23	33	44	+	2.5–3.5
	90–0 V	0					5	12–28
June 6	ca. 7 T	5	78	28	35	37	+	2.5–5
	90–0 V	0					8	16–26
June 13	ca. 7 T	5	64	9	28	63	+	3–6.5
	90–0 V	0					1	6
							5	9–28
June 20	ca. 7 T	5					+	4.5–9.5
	90–0 V	0					ca. 100	6–11
							1	27
June 27	ca. 7 T	5					+	4–10
	90–0 V	0					ca. 225	5–11
July 11	ca. 7 T	5					+	7–12
	90–0 V	0					ca. 140	7–13

* The numbers refer to the standard grades in fineness of bolting cloth as given by Dufour & Co.

the eggs classified accordingly. Stage 1 included all eggs with embryos varying in development from the single cell to the gastrula; stage 2 from the initial elongation to the single coil; stage 3 from that point to the final double-coiled embryo. At this station the proportions of stage 1 decreased and those of stage 3 increased until the disappearance of the eggs. Small *Sagittae*, down to 2 mm. in length appeared at the end of May and were still found up to the middle of June, but at the end of June there was none smaller than 4 mm., and on July 11 the smallest

taken were 7 mm. Evidently the spawning season in the Gulf was not continued beyond the middle of June. This sudden disappearance of the eggs coincided with an abrupt decrease in the numbers of the adults taken in the vertical haul with the larger net. The numbers of adults for the different weeks up to and including June 13 were 20, 5, 8 and 5 respectively. On June 20 a single one was taken, and after that date none at all. That the adults had not entirely disappeared is evidenced by the fact that on August 23 of the same year a deep tow made below 55 metres depth yielded 10 large *Sagittae* from 21 to 35 mm. long. Nearly all of these had well developed ovaries. It seems probable that spawning is not so limited in time in the Gulf as the results given in Table II would indicate. This view is corroborated by the finding in the early part of August, 1915, of individuals as small as 5 and 6 mm. in length generally distributed over the Gulf, even in the region where "Prince" station no. 30 is located, and at one place—"Princess" station no. 31—some as small as 2 and 3 mm. in length (Huntsman, 1919, pp. 459-461).

In the Bay of Fundy, however, we find a much longer season, (see Table III). As was expected after examining the ovaries of the adults, eggs were found in the plankton from April to October.

Owing to the large numbers in which the eggs are found there, the results from station no. 3 seemed to be best suited for a study of the proportionate numbers of the three developmental stages in the different months. At station no. 30 where the eggs developed normally and the season ended early, the proportion of eggs in stage 3 increased as the season progressed, so the fact that at station no. 3 from April to the end of July the number of eggs in stage 3 was never as large as the number in stage 1, together with the almost complete absence of the young *Sagittae*, leads to the conclusion that the eggs do not develop properly in the Bay. September was the only month in which stage 3 predominated, and it was also the only month when young *Sagittae* were found in large numbers. Even then, their numbers do not approach the swarms found in the Gulf in the early summer.

It is rather curious that in October the number of eggs in the first stages was again much greater than that in the later ones, and the number of young had also fallen off. This may have been due to the onset of cooler weather. The average of the temperatures at the surface and at a depth of 10 metres on each of the dates when tows were made is given in one of the columns of Table III. The abundance of the later embryonic stages and of the young shows a close correlation with the temperature, increasing up to September and then decreasing.

TABLE III.

"Prince" station no. 3.

Date	Temp. of upper 10 m. °C.	Depth of haul (m.)	Net no.	Eggs in percentages				*Sagittae*	
				No.	Stage 1	Stage 2	Stage 3	No.	Length (mm.)
1917									
Apr. 9	2.27	0–2 T	5	5	80	20			
		ca. 7 T	5	2	100				
		175–0 V	0					79	17–37
May 4	2.57	0–2 T	5	48	62	19	19		
		ca. 7 T	5	+	66	10	24		
		175–0 V	0					277	20–39
June 15	7.20	0–1 T	5						
		ca. 7 T	5	1	100				
		160–0 V	0					40	22–36
July 4	8.21	0–1 T	5	9	78	11	11		
		ca. 7 T	5	15	60	20	20	2	ca. 3.5
		150–0 V	0					19	22–33
July 31	10.68	0–1 T	5	82	49	27	24		
		ca. 7 T	5	+	41	31	28		
		175–0 V	0					4	ca. 30
Sept. 4	11.69	0–1 T	5	+	28	22	50		
		ca. 7 T	5	+	10	34	56	fairly numer-	
								ous	3–10
		175–0 V	0					31	21–36
								22	10–20
								12	4–9
Oct. 2	9.73	0–1 T	5	59	58	18	24	2	3 and 4
		ca. 7 T	5	28	78	11	11		

"Prince" station no. 4.

Date	Temp. of upper 10 m. °C.	Depth of haul (m).	Net no.	Eggs in percentages				*Sagittae*	
				No.	Stage 1	Stage 2	Stage 3	No.	Length (mm.)
1917									
May 25		0–1 T	5	3		75	25		
June 6		0–1 T	5	4	50	25	25		

TABLE III—*Continued.*

"Prince" Station no. 5.

Apr. 9	1.05	ca. 7 T	5	6	100				
May 4	3.16	ca. 7 T	5	60	68	15	17		
July 4	7.40	ca. 7 T	5	1	100				
July 31	8.56	ca. 7 T	5	6	50	17	33		
Sept. 4	10.21	0–1 T ca. 7 T	5 5	2	100				
Sept. 22	9.77	0–1 T ca. 7 T	5 5	2 6	50 83		50 17	1 6	3 2–7

Although the number of eggs found at stations nos. 4 and 5 was too small to give figures as to proportions which would be in themselves significant, the fact that they correspond with those from station no. 3 gives them meaning. Here, again, the young do not appear until September, the warmest month of the season.

Vertical Distribution of the Eggs.

Although the adults are restricted during the breeding season to the lower levels of the water, the eggs were found, as expected, near the surface. Reference to Tables II and III will show that there is no considerable or constant difference in their abundance at the surface as compared with a depth of 5 or 7 metres. We have no data as to their presence at greater depths. Although in stages 1 and 2 the eggs seem to be equally abundant at the surface and at 5 or 7 metres depth, there is some indication that in stage 3 some sinking has taken place, for where fairly large numbers were taken, as at station no. 30 on May 31 and at station no. 3 on May 4, July 31, and Sept. 4, the percentage at 5 or 7 metres depth was greater than that at the surface.

Horizontal Distribution of the Eggs.

Little can be said about the horizontal distribution of the eggs from the insufficient data at hand, except that they are numerous. where the adults are numerous, as at station no. 3, and few where few adults are found, as at station no. 5.

Horizontal Distribution of the Young.

The young are comparatively rare, and yet they are more widely distributed in the Bay of Fundy than are the adults. They are to be

found not only over the open bay, but also far up the estuaries, penetrating into waters where the adults are not to be found, at least during the summer.

At "Prince" station no. 21, in Kennebecasis bay, an arm of the St. John river, situated a considerable distance above the reversing falls, young individuals were taken in September, 1916, in the deeper water. Vachon gives the salinity of this water as from 18 to 21 0/00 (1918, p. 323). Unfortunately all the surface water samples taken at that time were lost through freezing, but the surface water appeared to be entirely fresh. In this bay many miles from any known habitat of the adults at that time of the year, young *Sagittae* were to be found in the brackish water underlying the fresh water of the surface. As the *Sagittae* were more abundant toward the mouth of the bay and occurred in the river connecting the Kennebecasis with St. John harbour and the Bay of Fundy, it is at least probable that all the individuals in the Kennebecasis had been carried in from the Bay of Fundy either as eggs or young.

The general observation has been made in recent years that young *Sagittae* are more plentiful in the estuaries than in the open Bay of Fundy, and that in the latter they are more plentiful where distance from land and shoals permits stratification of the water as at station no. 3, than where the proximity of land and shoals ensures constant mixing as at station no. 5. In the spring of 1920 an opportunity was afforded for determining the distribution of the young *Sagittae* in a rather long narrow estuary, the Magaguadavic river. This river empties into Passamaquoddy bay, and in its tidal portion a constant mixing of fresh and salt water takes place with the transition from one to the other not very abrupt. Four stations were established in this estuary, one at the mouth ("Prince" station no. 158) one at the head of tide (no. 161), and the remaining two in between. On June 19 at high tide tows with a net of no. 0 mesh were taken at the surface and near the bottom at all of the stations. On June 21 at low tide similar tows were taken at all stations except the uppermost. The *Sagittae* obtained in these tows are given in Table IV. From a consideration of these results it will be evident that at high tide the majority of the *Sagittae* were to be found in the middle or upper portion of the river, and that at low tide they had shifted down to the lower half.

The deduction might be made that this intermediate water of somewhat low salinity and high temperature is more favourable for the survival of these animals through the period of embryonic and early adult life than is that of the bay. Another explanation must not be neglected. The presence of the *Sagittae* in this estuary a number of miles from the habitat of the adults is *prima facie* evidence of their

TABLE IV.

"Prince" station no.		158		159		160		161	
Date	Depth	No.	Length (mm.)	No.	Length (mm.)	No.	Length (mm.)	No.	Length (mm.)
June 19	Surface	0	1	1	7	2	ca. 5	0	
High tide	Deep	2	6	10	5–10	15	5–12	6	5–9
June 21	Surface	0		0		0			
Low tide	Deep	10	5–10	.11	5–10	1	4		

having been transported thither. It will have been the inflowing deep current of strongly saline water that has carried them. They tend to remain near the bottom at least during the bright half of the day, as is shown in Table IV. This habit permits them to escape being carried from the estuary by the outflowing superficial current of somewhat brackish water. They should, therefore, tend to accumulate in the estuary. This explanation is sufficient to account for the facts that have been given.

DISCUSSION.

In the Magdalen shallows, as at "Prince" station no. 30, *Sagitta elegans* breeds very successfully. The picture presented in Table II is a uniform one. Eggs were very numerous on May 23rd, 1917, but no young had yet appeared. By May 31st hatching had begun, and by the middle of June egg laying was complete. Development in the egg must proceed very rapidly, as, although all stages were found on June 13th, none at all were taken on the 20th, and the young had advanced considerably beyond the stage at which they emerge from the egg. The maximum size of the young steadily increased from 4 mm. on May 31st to 12 mm. on July 11th. The physical conditions of the water in which there was this success in the development of the embryos, in the hatching of the eggs, and in the growth of the young, were the following, as furnished by Professor Vachon in advance of publication: During the period when the eggs were developing the temperature rose at the surface from 3.44 to 9.10° C., and at 10 metres depth from 2.40 to 5.09° C. By July 11th at both levels the temperature had nearly reached 14°C. The salinity during the whole period was quite constant, the extemes being 29.61 and 30.53 0/00. The densities also varied little, the range being from 1.02134 to 1.02429.

In the Bay of Fundy, as at "Prince" station no. 3, breeding is a failure. The spawning season is prolonged as compared with the

Magdalen shallows, but we are not prepared to state which condition is the normal one. Although eggs are produced for at least six months of the year, from April to October, recently hatched young were found only in the latter half of the period. Throughout the whole period, except in September, the early embryonic stages predominated, indicating an extremely high mortality of the embryos. Not only so but, with the same exception, the young were either absent or extremely rare, and these all recently hatched, indicating that the few that were hatched did not survive long. Only in September did the picture brighten temporarily. On the 4th of that month the hauls gave a preponderance of the later embryonic stages, a rather large number of young, and some of these with a length as great as 10 mm. This improvement seems to have been without effect on the final result as on October 2nd not only did the early embryonic stages again predominate, but there was no indication of the survival of the young hatched in September. At "Prince" station no. 5 the results were similar.

The physical conditions at Station no. 3 as furnished by Professor Vachon were,—the temperature rising from 2.27 to 12.19° C. at the surface and falling again to 9.77° C., that at a depth of 10 metres being somewhat lower; the salinity varying from 27.90 to 32.56 0/00 at the surface, and from 30.99 to 32.56 0/00 at 10 metres depth; and the density ranging from 1.02222 to 1.02604 at the surface and from 1,02396 to 1,02604 at 10 metres depth.

It must be confessed that in spite of the general differences between the Gulf of St. Lawrence and the Bay of Fundy, there is little in the physical data for the stations and periods under consideration to consider as responsible for the great difference in success in breeding in these two regions. For both the range in temperature is so great and so very similar as to make it necessary to exclude it as a factor. The salinities and densities at station no. 3 were on the whole higher than those at station no. 30, but not uniformly so. We are forced to conclude that a factor that may be responsible for the differences has yet to be demonstrated.

As it has been shown definitely that failure attends the reproduction of *Sagitta elegans* in the Bay of Fundy, the origin of the adult population of the Bay must be sought elsewhere. Great scarcity of the young has been found to obtain every year from the time (1915) when observations were begun, up to the present. In the autumns and winters of 1915, 1916, and 1917, the adults were found in large numbers, but during the following years they decreased, the lowest ebb being reached in the spring and summer of 1920. The Chaetognaths do not maintain a movement in any one direction, but dart somewhat aimlessly first in

one direction, then in another. There can be no doubt but that the very considerable fluctuations in their numbers is caused by their being carried into the bay in varying quantities from the adjacent Gulf of Maine. Currents sufficient for this have been shown to exist on the Nova Scotia side of the mouth of the bay. Herring larvae from eggs spawned outside the bay have been found carried in along the shore, and the drift bottle experiments conducted by Dr. J. W. Mavor have definitely proved the same movement to occur. The tributary bays and basins, although somewhat more successful than the Bay of Fundy itself as breeding grounds for *Sagitta*, do not provide sufficient young to account for the enormous numbers of adults that are frequently found there.

The sagittid population of the Bay of Fundy is kept up therefore, almost wholly by indraughts from the Gulf of Maine.

CONCLUSIONS.

(1) *Sagitta elegans* breeds successfully in the Magdalen shallows of the Gulf of St. Lawrence, as shown in the regular advance in development of the eggs and young with the progress of the season.

(2) It does not breed successfully in the Bay of Fundy, as shown by the predominance of early embryonic stages throughout the season and by the scarcity of young.

(3) The data of neither the temperature, the salinity, nor the density, afford grounds for considering any one of them as the factor responsible for this difference between the regions. Some factor associated with the general difference in conditions of the two regions must be sought.

(4) In the Bay of Fundy, the very limited success in breeding is correlated with the attainment of a high temperature, with the development in deep water of a special surface layer, or with the presence of estuarial conditions.

(5) The population of adult *Sagittae* in the Bay of Fundy is too great to be the result of local breeding, and must be considered as the result of indraughts around the southern end of Nova Scotia from somewhat distant waters.

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SCIENCE AS APPLIED TO NAVAL ARCHITECTURE AND SHIPBUILDING

By Rear Admiral D. W. Taylor
Chief Constructor, U.S. Navy

The application of science to the world inhabited by those who go down to the sea in ships is a very large subject and I need hardly say that I am not undertaking to cover it in detail.

The production of a large ship, particularly of a vessel of war, requires perhaps the co-operation of more arts and trades than the production by man of any other single object. This fact is seldom realized by the average man as may be illustrated by a peculiar situation.

A number of years ago, in the City of Philadelphia and State of Pennsylvania, a sailor from the U. S. Battleship *Maine* was arrested one night for alleged intoxication—this was nearly twenty years ago. Next morning the magistrate had planned to show leniency to the prisoner, but before dismissing him asked him what he did on the battleship. The sailor replied that he was the ship's bricklayer. Regarding this as persiflage and as rather reflecting upon the intelligence of the court, the magistrate promptly sentenced him to the limit of the law, but the poor man had told the exact truth. The battleship to which he was attached had a number of boilers of a new type involving the use of a large amount of fire brick in the furnaces and continual patching of the same as the old brick wore out, and this work took up the whole time of the prisoner.

The art of shipbuilding is one of the oldest known of man. Its origin is lost in the mists of antiquity but I understand that the earliest record of a ship, as distinct from a boat, canoe or other small craft, is found in Egyptian carvings dating some three thousand years or so before Christ.

The science of naval architecture, like so many other branches of science, developed somewhat slowly and, although one nation after another came to the front in this respect, we have to-day little information concerning the methods and principles adopted by their master shipbuilders. If we go back some thousand years before Christ we will find that the Phoenicians were building the best ships and carrying the commerce of the Mediterranean. Carthage later forged to the front but the Romans in time learned to build superior ships and acquired command of the Mediterranean. The Roman Liburnian galleys seem to have been of a superior type. Later the Vikings of Denmark and Scandinavia built most excellent ships. Tiny though they were as judged by present day standards they were seaworthy in the exceptionally

rough waters of Northern Europe and thoroughly suited for the conditions which they had to encounter. The Vikings of that time dominated not only their own waters but the English Channel and the seas around Great Britain. Only about 900 A.D., when King Alfred the Great had learned how to build better ships than those of the Vikings, did the British Islanders show ability to cope with the Northmen, and the command of the sea which Great Britain has held intermittently ever since dates back to the improved ships of King Alfred.

The ships of these ancient days were undoubtedly developed by trial and error and built largely by rule of thumb. The science acquired by each successive builder must have largely died with him.

The application of science, as we now understand it, to naval architecture is not much more than one hundred and fifty years old, and the progress of the application of science to shipbuilding during the last sixty years accompanying the development of iron and steel shipbuilding, has been greater than that of all previous time.

The French as early as the seventeenth century began applying the science of mathematics to shipbuilding, but probably the first scientific treatment of the whole subject was that of the famous Swedish naval architect and shipbuilder, Henry de Chapman, who published a treatise on shipbuilding in 1775. While English speaking people were leaders in the art they seem to have long been rather backward in the science. For instance, the dearth of scientific literature on shipbuilding in the English language was so great that as late as 1820, Doctor Inman, the head of the Royal Naval College and School of Naval Architects in Portsmouth Dockyard, England, which was established about that time, published a translation of Chapman's work, then nearly fifty years old, for the instruction of English students of naval architecture. Chapman's work, as might be expected, consisted largely of empirical rules and, although far in advance of his day and much of it still applicable to sailing ships, many of his ideas are now known to have been erroneous.

Toward the end of the sailing-ship era we find Ruskin summing up an opinion of the ships of his day. In a famous passage he said:

> "Take it all in all, a ship of the line is the most honorable thing that man as a gregarious animal has ever produced. By himself, unaided, he can do better things than ships of the line; he can do poems and pictures and other combinations of what is best in him. But as a being living in flocks and hammering out with alternate strokes and mutual agreement what is necessary for him in those places, to get or produce the ship of the line is his first work. Into that he has put as much human patience, common sense, forethought, experimental philosophy, self-control, habits of order and obedience,

thoroughly wrought handiwork, defiance of brute elements, careless courage, careful patriotism, and calm expectation of the judgment of God as can well be put into a space 300 feet long and 80 feet broad, and I am thankful to have lived in an age when I can see this thing done."

Whatever may be said of the ships of the line of to-day, few people regard them as things of beauty, and I fear Ruskin would not have shown the same enthusiasm over them; but as achievements of mechanical science, the ships of the present day and generation have made enormous progress from the sailing ship of the line. Ruskin's 300 feet of length has tripled and the ship of the line of to-day is ten times or more as large, measured in terms of weight, as the old sailing ship of the line. This progress could not have been made had not the naval architect utilized fully the enormous development of science since the sailing ship days.

Consider now very briefly a few of the actual branches of science which play a part in connection with ships.

While out of the sphere of shipbuilding, I want to touch upon one notable branch of science, possibly the oldest science there is, which, largely sterile as regards workaday affairs ashore, is essential to the seaman and applied every day by him. I refer to astronomy. The ancient astrologists—the leading men of science of their day—ascribed to the stars great influence upon the affairs of men. I think I am correct in saying that at the present day the work of the astronomer, intensely interesting and important as it is, has its only practical value of general application in the accurate determination of time. The rays of light that render the stars visible to us to-night left them long ago, thousands of years in some cases I believe. What we may learn concerning them is interesting but not of practical importance so far. Some day, possibly very soon, the close and incessant study of the sun which has been going on for so many years will be fruitful as regards weather prognostications, and it may be that in the future astronomy will show results which will be of great pracitcal importance to the whole of a workaday world. The sailor, however, for many years has made his safe and sure passage from one point of the earth's surface to another by utilizing the work of the astronomer in the shape of accurate predictions of the position of the heavenly bodies in reference to the earth and the accurate determination of time made possible by the patient astronomer.

May I illustrate by a very brief and simple concrete example. At 10 o'clock this morning at Toronto the sun's angle above the true horizon was 22° 31′ 41″. But this was not the only spot upon the earth where the sun had this altitude at this time. The locus of such spots formed an enormous circle which, leaving Toronto to the eastward, passed through

the Gulf of St. Lawrence and the Atlantic, striking land in Morocco, traversed Africa passing near the Cape of Good Hope, passed within 300 miles of the South Pole, entered the Pacific south of Cape Horn, came northward in the Pacific striking the American continent at Manzanillo Bay, Mexico, entered the United States in Texas and passing through the States of Arkansas, Indiana and Ohio returned to Canada and Toronto.

At two o'clock this afternoon in Toronto, the sun's altitude was 22° 34′ 15″. The circular locus of equal altitude passed through New York then southward in the Atlantic, through the eastern portion of Brazil and on nearly to the South Pole. Swinging northward, it passed through New Zealand, the Fiji Islands, westward of Hawaii, struck the continent again near Vancouver and so back to Toronto. Each of these circles contains an infinite number of points, but they intersect each other in but two, Toronto and a point in the southern hemisphere only 300 miles from the South Pole.

From a single time sight, as it is called, namely, the determination of the altitude of a heavenly body at a known time, the navigator can determine a locus upon which he must be. A second time sight at a second known time determines a second locus which crosses the first. It is this principle which is largely relied upon by the modern navigator and, with his astonishingly accurate instruments for recording time, he can determine his position with great accuracy providing he can see the heavenly bodies. Unfortunately, as we know, this is not always possible. A recent development of science has enormously facilitated accurate navigation, particularly in the vicinity of land where accuracy of navigation is most important. By means of radio apparatus the direction of a ship from each of two radio stations ashore can be determined, and hence the position of the ship herself. This is being done day by day off our coasts. I am betraying no secrets when I state that one very valuable means used in coping with the German submarines during the late war was the determination of their positions, approximately, through receipt of their radio signals at shore stations of the British Isles.

But to return to the question of the various sciences. Of course mathematics are essential and the science of naval architecture finds use for many of its branches. To instance a simple case, accurate calculations are of the greatest importance in connection with shipbuilding. The displacement of the ship is the capital upon which the naval architect has to work and it is necessary that he calculate this displacement with the utmost accuracy. The mathematics of mensuration are neither

difficult nor abstruse but much ingenuity has been expended in devising simple forms and methods for ship calculation.

In spite of our desire for shortening work, it is usually regarded as essential that forms of such work should contain an automatic check. For instance, when determining the volume of a ship below water we calculate the areas of a series of transverse sections and then sum them longitudinally and from the same original ordinates calculate the areas of a series of horizontal sections and then sum them vertically. If the identical result is obtained by the two methods we naturally conclude it is correct. I recall, however, one example in my experience where such a result was wrong. Intermediate errors produced the identical error in each result. Fortunately it was not material.

To instance another application of mathematics. It is this science in the end which has made possible the modern systems of control of the firing of the great guns which permit them, with a considerable degree of accuracy, to drop a shell weighing as much as a ton on a comparatively small target at distances of twelve to fifteen miles. If the ship and its target were both fixed, mathematics would play a comparatively small part. The range finder, developed from the science of physics, would be the primary factor involved, but when a shell has to spend many seconds in the air (nearly half a minute at extreme ranges) from the time it leaves the gun until it reaches its mark, when the firing ship and the ship fired at are moving at variable speeds, each with a possible angle of 360 degrees in azimuth, even an accurate knowledge of the distance separating the ships firing and fired at, at the instant of firing or a short time before, is of comparatively little value. Other variables mentioned above, all come in and the accurate control of fire of the present day is based largely upon instruments or mechanisms which permit the instantaneous solution of problems containing as many as half a dozen variables.

Chemistry is a science just as important in shipbuilding as any other branches of engineering. For men-of-war the problems involved in the manufacture of propellent powders and high explosives in safe and desirable forms are essentially chemical problems. Chemistry, also, is essential in metallurgy, which plays one of the most important parts in shipbuilding by providing numerous varieties of steel, ferrous alloys and non-ferrous metals, which are used in the various parts of the ship and its equipment. Of course most of these materials are in general use but some of them have been developed solely for the use to which they are put on ships and there are many peculiar chemical problems. I recall one case which illustrates such a problem. As we all know, aluminum has extreme lightness and adequate strength for

many purposes, such as cooking utensils. A number of years ago in the United States when building some torpedo boats, we sought to save weight by the use of aluminum in various places where strength was not important. We found however that the aluminum sooner or later in the presence of salt water or even salt air degenerated into a chalky substance. Curiously enough a recent alloy of aluminum, known as duralumin, seems quite resistant to destructive forces which soon disintegrate pure aluminum.

The science of physics has played a particularly prominent part in men-of-war of late years. The branch of optics alone has given us the theories of and made practicable the various range-finding instruments which, in conjunction with the fire-control systems, make possible the accurate firing of guns and torpedoes. Even acoustics is a branch involved in connection with all vessels. They all require the transmission of intelligence by means of sound. Other methods of transmission of intelligence and orders are used however as it is essential for men of-war that the systems of communication be adequate and so arranged that they will not fail us by probable damage from the enemy, or break down in the midst of the noise and confusion of battle, or because of the high mental tension at such times of the personnel using them.

The sciences of physiology, medicine and hygiene seem alien to the naval architect but cannot be ignored in connection with the construction of any ship. During war and under war conditions it is sometimes necessary to operate with little regard to hygiene, but during the long years of peace a large battleship must be the healthful and as far as possible the happy home for anywhere from 1,000 to 1,500 men. At best these men live under somewhat crowded conditions, and what we term in the Navy "berthing and messing facilities," which correspond to the housing, and feeding conditions in ordinary life must be based on the most modern scientific principles.

The ventilation of a large man-of-war involves many problems other than those of hygiene. Such vessels are made up of a large number of compartments or cells of which the majority are watertight and airtight. Some of them are never occupied by human beings except for such purposes as cleaning and painting. Double bottom compartments and oil fuel tanks are in this class. Some compartments such as storerooms and magazines are occupied at intervals but not continuously. Fire rooms and engine rooms and dynamo rooms are occupied continuously in the service of the ship and need to be cooled as well as ventilated. While we use as living quarters every part of the ship which receives natural daylight and ventilation, it is still necessary for men to live in spaces where they must rely upon artificial light and ventilation. Our ven-

tilating pipes and apparatus must not only supply the crew with adequate air but must be planned so that they will not allow water to pass from a compartment flooded by damage in action to another still intact.

To insure efficiency in battle, the design must take careful cognizance of what medical science has ascertained as to the limitations of human endurance when working at high pressure under adverse conditions. In addition to the general hygienic considerations to be taken into account throughout the whole ship, a large first-class ship at present carries a completely equipped medical establishment or hospital, including operating rooms, isolation ward for contagious diseases, special examining and treatment rooms, dental facilities, etc. During late years there has been developed a specialized type of hospital ship proper, which accompanies the fleet and furnishes it with hospital facilities essentially equal to those found in the best hospitals ashore.

Electrical science pervades a modern man-of-war from stem to stern. On our latest capital ships electrical apparatus is used to drive the ship, to steer the ship, to train and fire the guns, to hoist the anchor, to raise the ammunition, to turn the turrets, to ventilate the ship, and for an infinite number of minor purposes. 180,000 H.P. = Electric power of a city of 700,000.

During the last ten years or so the growth of wireless telegraphic methods of communication—radio we call it for shortness—has been such as to establish virtually a new branch of science. Radio has found its major use so far in the communication between ships at sea with other ships and with the land. I need not enlarge upon its value in this field but desire simply to call your attention in passing to the fact that useful and used as it is on land, radio telegraphy has been developed mainly for use on shipboard.

I hope I have said enough to make clear the fact that practically every branch of science and engineering (which is applied science) must or can enter into the design of the great ships of the present day.

The great advantage of the scientific development of naval architecture which has been so notable during the last fifty years or so, is that we are enabled to progress by long steps rather than short. The naval architect seldom evolves a ship out of his own consciousness, as the German philosopher undertook to do with the elephant. The first estimate or approximation of a ship to meet certain requirements must be based largely on previous practice and experience. Before the development of scientific naval architecture in its modern sense, this resulted in rather slow step-by-step progress from one ship to another. By applying scientific analysis and methods to the results of the past, however, we are now able to make our steps much greater, so that

during the last quarter of a century advances which would have been bold to rashness at an earlier time, have become almost routine. This rule of step-by-step progress referred to above, has at least one astonishing exception: Nearly seventy years ago a famous English civil engineer and bridge builder, Brunel, turned to shipbuilding, maintaining that the larger the ship the more economical and efficient her operation,—a perfectly sound scientific principle. Brunel attracted large capital, and in association with Scott Russell, a shipbuilder and naval architect finally produced the *Great Eastern* which was indeed a giant to a pigmy when compared with the other iron steamships of her day,—(we must not forget that iron shipbuilding was a very recent art in those days). The *Great Eastern* had her keel laid in 1854, was launched in 1858 after many difficulties, and put in service in 1859. She fell short of the expectations of her designers in some respects, and was not a commercial success mainly because she was too big a step forward, but that she was built at all was truly a remarkable accomplishment and due largely to the fact that Brunel utilized to the utmost the engineering sciences of the day. Not until 1899 was a vessel the size of the *Great Eastern* again built.

Let us consider now a little more in detail a few applications of science to essential features of the ship. Three primary problems with which the naval architect has to deal are the stability, the strength and the propulsion of the ship. One thing that is obviously necessary for a successful ship is that it should not capsize. The science of mathematics has been applied to investigating the question of stability of vessels,—stability being the measure of the ability of a ship to remain upright or return to the upright when inclined by wind or waves. In the ships of ancient days, stability was largely gained by carrying ballast or heavy weights low down, the amount and location of such ballast being frequently determined by trial after the ship was completed. This meant that, except when copying a preceding vessel, it was not known in advance whether a proposed design would be satisfactory as regards stability. I believe about the first person to apply scientific methods to this problem (at least the first of record) was a French mathematician named Bouger, who developed the idea of the metacenter. In mathematical language, the metacenter is the center of curvature of the locus of the center of buoyancy of the vessel as it is inclined. As a practical proposition the metacenter is the limit above which we cannot locate the center of gravity of the ship without having her initially unstable and unable to float upright. The greater the distance of the center of gravity below the metacenter, the stiffer the ship is initially, or the harder to heel from the upright position. It is supposed

that the word "metacenter" is derived from the Greek work *meta*, limit or goal, and the word center, meaning the limit of the position of the center of gravity.

The position of the metacenter depends upon the geometrical form and dimensions of the ship. Perhaps a homely illustration may clarify this conception of the metacenter which appears to be a mystery to many laymen. Suppose you take an ordinary rocking chair with a circular rocker, (rocking chairs are not made with circular rockers as a rule, but they are sufficiently near the circular for the purposes of my illustration). The rocker is rather flat and the center of its circle is well above the seat of the rocker and even above the arms. So ordinarily the center of the curvature of the circular rocker is above the center of gravity of the chair and the latter is above the center of gravity of the chair and the latter stays upright. The flatter the rocker and hence the higher the center of the circle, the stiffer the rocker is. If, however, one takes a table and secures it on the seat of the chair so that the plane of the table is above the center of curvature of the rocker, and then proceeds to pile weight upon the table, it is only a question of time when the center of gravity of the combination will rise above the center of the rocker circle, in which case the chair will promptly capsize. Before loading the combination with top weight, the chair if tilted will oscillate quickly and sharply. As we pile on weight, the period of oscillation will increase with decrease of metacentric height, and the period will increase indefinitely as we approach a metacentric height of zero, the motion of oscillation becoming more and more sluggish.

After Bouger developed the conception of mathematical methods for calculating the position of the metacenter of a ship, Atwood, an Englishman, carried the matter further by calculating the righting moment or righting tendency which would tend to bring the vessel upright if twisted over in smooth water. For many years the metacentric conception, which applies only to initial conditions, appears to have been sufficient for practical purposes. About fifty years ago, however, there was a marine disaster which brought home very strongly to naval architects the fact that there was another factor involved in stability. You may recall that in the Civil War the United States built a number of monitors as developed by Ericsson, the monitor being essentially an armored vessel with a very low freeboard and carrying its guns in turrets on a deck not more than two or three feet above the water. The Ericsson monitor was purely a steamer, being without sail power. A distinguished English officer, Captain Cowper Coles, took up with enthusiasm the monitor idea, and as a result of his campaign there was built in England a large low freeboard vessel of the monitor type, called the *Captain*,

which also had full sail power. Naval architects of the English Admiralty were not enthusiastic over the type, and two of the younger ones made calculations which indicated to them that the *Captain* was not safe. But early reports concerning the vessel and experience with her indicated that she would be a great suceess, so little attention was paid to the theorists and their application of science until on September 7, 1880, in the Bay of Biscay, with a moderate gale blowing, the *Captain* capsized with a loss of 481 lives, including Captain Coles himself. The vessel was perfectly safe until conditions were such that she heeled over enough to bring her deck edge well under water. After that, her righting force rapidly fell off, and at a comparatively small heel became negative, resulting in capsizing. Under the weather conditions existing, the force of the wind against the sails of the *Captain* was sufficient to heel her beyond her safety angle, and over she went.

The prompt and thorough investigation into this disaster emphasized the fact that the metacentric height is not the only factor which must be considered in connection with stability. For safety, the range of stability or the range over which the heeled vessel retains a tendency to right is important. A vessel with a very small metacentric height may be perfectly safe if it still retains a righting tendency at a large angle of inclination. Large range of stability, or tendency to right at large angles of inclination, is a feature associated primarily with high freeboard. On the other hand, low-freeboard vessels have a comparatively short range of stability, but they also may be perfectly safe if their metacentric height and initial stability are very great so that a large amount of work has to be done to incline the vessel through its comparatively short range of stability.

The monitor type with very low freeboard and very short range of stability but great metacentric height, giving perfect safety, has been compared to a chip, which always sets itself parallel to the surface of the water. A chip is obviously not in danger of capsizing in a seaway. At the other extreme from the monitor we have the deep draught high freeboard vessel with little or no initial stability but a great range. Here the extreme case may be regarded as that of a pole weighted so as to float upright which will return to the upright in time no matter how much the sea may deflect it temporarily.

This whole question is now fairly well understood, and the naval architect—provided his calculations are correct—is enabled to adjust his metacentric height as he will by varying the proportions and dimensions of the ship to suit the position of the center of gravity and type of vessel, the uncertain factor in connection with the preparation of a design being the location of the center of gravity, which is the center

of gravity of every weight in and on the ship running literally to many thousands of items upon a 40,000-ton battleship. Naturally this is very difficult to estimate with great accuracy during the design stages of a vessel. However, we can calculate very exactly the position of the metacenter from accurate plans of the lines of a ship and for a completed ship we can determine very accurately the distance of the center of gravity below the metacenter and hence its location in the ship. This is done by means of the so-called "inclining experiment." With the ship floating freely in still water we move a known weight a known distance transversely and measure carefully the resulting inclination of the ship. From these results we can calculate by simple formulae the distance of the center of gravity below the metacenter.

The usual conception is that the stiffer a ship is, or the greater the metacentric height, the greater her safety from the point of view of stability. This is true generally but if a vessel is given too great metacentric height she is most uncomfortable in a seaway, responding like the chip to every passing wave and her motions may become so abrupt and jerky as to be dangerous. Passenger vessels have often crossed the Atlantic in perfect safety with zero initial stability or even a slightly negative metacentric height, their freeboard and shape giving them perfect safety through a range of stability of as much as 90° and their small metacentric height making them unusually comfortable in average weather.

When the naval architect comes to consider the question of the strength of his designs, he is forced to realize that exact scientific methods are not yet applicable to this problem. The designer of a great bridge is able to fix in advance the loads which his bridge must provide for, and then do his designing accordingly. The naval architect cannot do this. The strength of a ship should be such as to enable it to withstand, under all conditions, the waves of the sea, but the latter are infinite in variety and there must always remain some uncertainty as to just what will be the strains upon the ship due to the action of the sea. However, although we cannot treat this matter by the accurate methods of science, we can make an approximation of the most severe conditions, based upon previous accumulated experience and observation, and then apply the usual methods.

In spite of the many thousands of observations that have been made on waves of the sea, there is yet no complete agreement in regard to their limiting characteristics, such as length and height and the relations existing between these dimensions. We do know that waves have extremely wide ranges of characteristics. We may have, for instance, a wave five hundred feet long,—that is, five hundred feet from crest to

crest, and only a few inches high,—that is, only a few inches between the level of the crest and the level of the hollow. Again, we may have a wave of this length, thirty feet or even forty feet high between the crest and hollow. Even in the stormy North Atlantic, however, such heights are unusual, and forty feet is probably about the limit of regular waves generated in deep water by unusually severe and long-continued storms. This exceptional height, however, is liable to be materially surpassed by abnormal waves, the result of superposition of one wave system upon another. In such case, however, the waves do not manifest themselves with regular crests, but the abnormal heights are more like isolated peaks. The natural tendency when looking at waves is to over-estimate their height, and accurate determinations of wave heights are difficult to make. The excessive heights reported now and then will be found to be estimates by eye in every case. The highest wave of which I have been able to discover an accurate record was almost exactly sixty feet high.

Returning to the question of the strength of ships: If the sea were always at rest, the problem would be very simple. The big strains result from the waves. There is one feature in this connection where a ship differs radically from the usual structure. The determination of strength by "rule of thumb" methods and step-by-step development leads in the majority of cases to excessive strength. The natural tendency is to err on the safe side. For fixed structures on shore, and even for many pieces of moving machinery, excessive strength is not necessarily a fault except from the point of view of cost. On a ship, however, too much material, while not as grave an error as too little, is highly objectionable from other considerations than cost. Every ship is built to perform some distinct service, and, as a floating body, can carry for all purposes only a weight equal to that of the water which it displaces. Every pound which goes unnecessarily into the structure of the ship itself is a dead loss to the disposable weight available for the aim or object for which the vessel is designed. Hence, though the necessity for adequate strength is paramount, excessive strength or unnecessary weight on a vessel is a grave fault, and the scientific study of this most important question must ever be made with that consideration in mind.

In spite of the complication of the question, the underlying theories are comparatively simple. Investigation has shown that for a given ship the most severe stresses in waves of a given height are associated with wave lengths from crest to crest the same as the length of the ship. When bow and stern are in the crests of successive waves, and the midship part in the hollow, the vessel is said to "sag," for obvious reasons. When bow and stern are in hollows and the midship section supported by the crest, the vessel is said to "hog." The strains vary with the height

of the wave, but the majority of our calculations refer to the more or less standard condition when the height of the wave is one-twentieth of the length. The ship's structure as a whole is considered as a built-up girder with upper and lower flanges and connecting webs. Knowing the loading of the ship, it is possible, by methods which are tedious but not difficult, to determine the bending moment of a vessel at any point in any wave distribution and hence from the known characteristics of the section of the vessel at that point we can calculate the stresses upon the material of the hull structure.

We come now to the crucial question, how nearly do these stresses and strains which we obtain by these calculations approach what we actually find in service? It is possible, with modern strain indicators, to measure stresses of a ship in a seaway, but such experiments are exceedingly tedious and if properly done are expensive. In 1903, after a destroyer had broken in two in Great Britain, numerous experiments were made under the direction of Professor J. Harvard Biles in order to obtain first-hand data upon stresses of ships at sea. It was found that the results obtained were not inconsistent with those to be expected from the standard methods of calculation, but they were not sufficient to say that they extended to ships other than the particular vessel experimented with. The real method which we rely upon in this connection is a statistical and somewhat indirect one. Suppose, for instance, we have a number of 5,000-ton vessels and find that, applying to them our standard methods of computing stresses, the deck tensions vary from, say 5 tons per square inch to 12 tons per square inch. If now we find in long service that the vessels whose calculated stress is ten tons per square inch and over show defective strength not necessarily by breaking in two but by joints opening, rivets shearing, etc., while the vessels of lower calculated stress give no trouble, we conclude that for such a vessel we should make our plates so thick that the standard calculated stress will not exceed eight or possibly nine tons per square inch, leaving some margin below the danger point. It is essentially by this method that we fix the strength of vessels to-day. Classification societies, such as Lloyds, have been collecting information as to casualties, signs of weakness, etc., in service for many years, and nearly fifty years ago scientific papers in the British Institution of Naval Architects laid down in full the principles which I have briefly outlined above.

There is one point I may mention in this connection which shows that our methods, adequate though they may be for practical purposes, still leave something to be desired from the point of view of scientific principles. If our methods were scientifically accurate they would show the allowable stress per square inch the same in the case of large and small

vessels. As a matter of fact, we find that large ships are adequately strong when their stresses, calculated in the somewhat semi-empirical method indicated above, are nearly twice those of small ships. This does not mean that steel in a twenty thousand ton ship is twice as strong as steel in a five thousand ton ship, but simply that our standard methods do not apply in similar ratio to large and small ships.

While the greatest strains upon a vessel afloat in service occur in rough water, there is one operation during the building which is liable to tax severely the strength of the vessel unless careful investigation and preparations are made in advance. I refer to the launch. Except on the Great Lakes of America, the almost universal practice is to launch vessels stern first in the direction of their length, which means that supported on a wooden sled they toboggan, as it were, down a timber slide, lubricated with tallow and oil or the equivalent. The length and inclination of the ways upon which the vessel slides, and the inclination of the keel of the vessel to the horizon in the position in which she is built, must be carefully calculated to insure, first, that the vessel does not tip over the end of the ways and lift her bow, which would result in crushing her, due to concentration of weight at the end of the ways, and, second, that the vessel does not lift her stern so soon as to produce a bending moment which would break her in two. A third minor factor is that it is undesirable to have the bow of the vessel, as she clears the end of the ways, drop too far, although this is not a matter of importance if the two major matters referred to above have been properly taken care of. All of the calculations necessary to insure a satisfactory launch must be made, and the launching ways fully planned before the keel of the vessel is laid.

The launching weight of a 33,000-ton battleship will be about 15,000 tons, and the transfer of this large mass from quiescent repose, upon blocks shored to keep them thoroughly rigid and stable, to the condition afloat, is one of the most spectacular incidents in shipbuilding. A successful launch is a very pleasing sight and apparently a very simple and easy performance. Few of the spectators realize that it was planned virtually to the last detail before the first keel plate of the vessel was laid, or for that matter, before the keel blocks themselves were located and graded.

I will say a few words in conclusion concerning one branch of naval architecture which during the last fifty years has, I believe, profited more than any other by the application of science both in the establishment of correct theories and the abolition of older and in many cases grotesquely erroneous ideas. I refer to the question of speed and power. Our modern ideas on this subject are due primarily to William Froude,

originally a civil engineer associated with Brunel and Scott Russell in the days of the *Great Eastern*, whose ideas were taken up by the British Admiralty about 1870. Upon William Froude's death in 1876, his mantle fell upon his son, Mr. R. E. Froude, who continued and expanded his father's work. The elder Froude's outstanding achievement was the demonstration of the reasonable accuracy of his "Law of Comparison," commonly called by naval architects "Froude's Law," by which, from the resistance of a small but accurate model of a ship, towed at low speed, we can closely estimate the resistance of the full-sized ship at her actual speed. Froude's Law is a particular case of the general law of mechanical similitude which seems to have been first enunciated by Newton and recognized in the last century by French mathematicians. Mr. Froude seems to have been the first to obtain practical results from it.

The fundamental principles of Froude's method are very simple. He divides the resistance of a ship moving through the water into two portions—first, that due to the friction of the water upon the surface, and second, the residuary or remaining resistance due to the formation of the waves and other disturbances in the water, caused by the ship's passage. To determine the frictional resistance, Froude made a number of experiments with plane surfaces of various lengths towed at various speeds, and his results are still standard, although they did not cover as wide a field as would be desirable. It is to the residuary resistance—a minor factor for low-speed vessels, but a major factor for vessels making high speed—that Froude's Law of Comparison applies.

Suppose we have a 500-ft. vessel which we wish to drive at 30 knots, and make an accurate model of the hull 20 feet long, the ratio of dimensions being as 20 to 500, or 1 to 25. We tow a model at what we call a "corresponding speed" to the speed of the full-size ship, the corresponding speed being as the square root of the ratios of the linear dimensions, in this case as the square root of 25, or as 5 to 1, so we tow the 20-ft. model at 6 knots, or one-fifth of the 30-knot speed for the full size ship and determine its residuary resistance by deducting from the total the frictional resistance calculated from Froude's coefficients. This residuary resistance needs simply to be multiplied by the ratio of the displacements to determine the residuary resistance, at 30 knots, of the full-sized ship. In this case the linear ratio being 25, the displacements are in the ratio of the cube of 25, or 15,625, so we multiply the residuary resistance of the model at 6 knots by 15,625 and obtain the residury resistance of the 500-ft. ship at 30 knots.

Froude's methods have been applied to the problem of the propeller with great success. But here we find a partial failure, not of Froude's Law, but of our ability to properly apply it. Strictly speaking, the

Law of Comparison requires that at corresponding speeds of ship and model, the pressures of the fluid around ship and model should be in the ratio of the linear dimensions of the models. This is substantially fulfilled when we tow a model through a model tank. The pressures of water are proportional to the linear dimensions, and the atmospheric pressure, which is not proportional to the linear dimensions, being constant for model and ship, has no effect upon the resulting phenomena. In fact, with minor exceptions, the disturbances set up by model and ship in the water are the same as if there were no air pressure, as if model and ship were operating in a vacuum. When we come to a propeller, however, the case is different. This operates completely submerged, and the pressure of the air being equivalent to some 33 feet of water, affects the model propeller differently from its effect upon the operation of the full-size propeller. The practical result is that the full-size propeller experiences "cavitation," as it is called, while the model propeller at corresponding speed does not show cavitation. Cavitation is the name that we give to the condition where the water around a propellor operating at high speed, under high pressure, is unable to follow the blades which tear holes or cavities in the water, resulting in a rapid and pronounced loss of efficiency. If one takes a stick and draws it rapidly through the water of a stream, it will be observed that the water is unable to follow closely the stick which leaves a cavity behind it. The cavitation of a propeller is somewhat the same kind of phenomenon. If we could test a model in a vacuum or partial vacuum, we could fully reproduce the phenomenon of cavitation on the model. We can also place a model propeller in somewhat the required condition by testing it in hot water. There are obvious difficulties in such experiments, however, and in dealing with propellers we are compelled to restrict the application of the Law of Comparison to conditions where cavitation does not appear in the full-size propeller. Incidentally this covers the practical field, since we of course avoid having propellers which show cavitation with the resulting loss of efficiency. Unfortunately our knowledge of the border line between cavitating and non-cavitating propellers is not exact, the cases of cavitation of full-sized propellers being always unintentional.

I need not enlarge upon the obvious value of the tool which Froude supplied the naval architect. We have here a most beautiful illustration of scientific methods applied in practice. We do not have to build a ship or resort to elaborate calculations to determine its resistance. We can build a small model ten or twenty feet, and months or even years before the ship is finished, from the tests of this model, estimate with great accuracy the performance of the ship. But the outstanding value of the method is the fact that we can quickly and cheaply modify our

small model and in that way determine the most advantageous form to meet our conditions. For instance, we are building in the United States some large and fast battle cruisers. Some years ago when these were in the early design stages, there were made and tested in the Model Basin at Washington, (which follows the Froude method) upward of twenty possible models for these vessels, with the result that the resistance of the model finally adopted was nearly fifteen per cent. less than that of the first model tried. Since this Model Basin was established a little over twenty years ago we have made and tested for resistance some 2,400 models nearly all of the 20-ft. length. It might seem at first that, with this mass of accumulated experience, the whole ground has been covered. Of course, that accumulated data is of the greatest value, and when a new type of vessel is under consideration we can estimate very closely the speed and power without making a model, but when we actually come to the final design stage we still find it possible to make improvements, and regard the work of making and testing several models as essential.

I might say here that the problem of the naval architect in dealing with actual vessels is not essentially that of making the vessel of the minimum resistance for the displacement. In the case of a given vessel we could nearly always design one of less resistance, but resistance is not the only factor to be considered. For instance, a number of years ago we were investigating the question of a vessel of about four thousand tons displacement which was required to make a very high speed, or rather a speed very high for those days. We found that if we made this four-thousand ton vessel 450 feet long the resistance would be just half of what it would be if made 350 feet long. Unfortunately for the naval architect, however, length is objectionable from nearly every point of view except that of speed. It involves, for instance, materially greater hull weight because a long vessel is more stressed in a seaway than a short vessel. We finally made the vessel 420 feet long, thus gaining the greater part of the benefit of length without suffering the objections due to excessive length.

We often find inventors who believe that there is some great merit in some particular shape of line, the merit being lost if the line is varied by a hair's breadth. We find as a matter of fact that the detail shape of lines is rather a secondary feature in connection with resistance. The primary factor in obtaining high speed is length. For low speed vessels, length is less important. Next to length the most important thing is the area of the maximum or midship section as we call it. Details of shape have little influence. The most desirable solution in one case is liable to vary very much from that in another. For instance, for

vessels of moderate speed—moderate in proportion to their length—we find, broadly speaking, it is desirable to make the ends fine (that is to say *thin* in ordinary language), and the waterlines rather hollow if anything. Such vessels may often advantageously be made relatively broad of beam in order to gain a large midship section, the displacement being concentrated amidships and taken from the ends. For very high speed vessels, however, such as destroyers, curiously enough, the ends can advantageously be made quite full and blunt, it being desirable in this case to make the area of the midship section much smaller than in the case of vessels of moderate speed. The fact that the most desirable features of form vary so with size and speed of vessel is alone sufficient to require careful investigation of each important case by Froude's law, and as a matter of fact no country which builds ships of any importance is now without at least one experimental tank following the principles discovered by the modest scientist who, fifty years ago, built the first such establishment in his garden at Torquay, England.

DATA ON U. S. NAVAL VESSELS USED IN ILLUSTRATION

Name	Year Authorized	Length Over all	Displacement	Batteries
SUBMARINES			Tons	
Holland	1896–1899	53′-10″	75 Surf.	
S-5	1916–1917	231′- 0″	854 "	
T-1 (AA-1)	1914	269′- 9″	1107 "	
DESTROYERS				
Hopkins	1898	248′- 8″	408	2-3″-6-6 pdr.-2-18″ tubes.
Preble	1898	250′- 2″	420	2-3″-5-6 pdr.-2-18″ tubes.
Reid	1907	293′-10″	700	5-3″-3-18″-tubes.
Henley	1910	293′-10″	742	5-3″-3 twin 18″ tubes.
Cummings	1911	305′- 3″	1020	4-4″-4 twin 18″ tubes.
Davis	1914	315′- 3″	1071	4-4″-4-21″ triple tubes.
Gwin	1915	315′- 6″	1125	4-4″-2-3″ 23 cal. A.A. 4-21″ triple tubes.
McCawley	1917	314′-4½″	1215	4-4″-1-3″ 23 cal. AA. 4-21″ triple tubes.
BATTLESHIPS				
Oregon, Indiana, Massachusetts	1890	350′-11″	10288	4-13″-8-8″-4-6″-20-6 pdr.
Iowa	1892	362′- 5″	11346	4-12″-8-8″-6-4″-20-6 pdr.
Kearsarge and Kentucky	1895	375′- 4″	11520	4-13″-4-8″-14-5″-20-6 pdr.
Wisconsin, Alabama, Illinois	1896	373′-10″	11552	4-13″-14-6″-16-6 pdr.
Maine, Missouri, Ohio	1898	393′-11″	12500	4-12″-16-6″-6-3″-8-3 pdr.
Virginia, New Jersey, Georgia, Nebraska, Rhode Island	1899	441′- 3″	14948	4-12″-8-8″-12-6″-12-3″-12-3 pdr.
Connecticut, Louisiana, Vermont, Kansas, Minnesota, New Hampshire	1902–1904	465′- 4″	16000	4-12″-8-8″-12-7″-20-3″ 12-3 pdr.

DATA ON U.S. NAVAL VESSELS USED IN ILLUSTRATION—*Continued*

Name	Year Authorized	Length Over all	Displacement	Batteries
South Carolina and Michigan	1905	452′- 9″	16000	8-12″-22-3″-2-3 pdr.
Delaware and North Dakota	1906–1907	518′- 9″	20000	10-12″-14-5″-4-3 pdr.
Florida and Utah	1908	521′- 6″	21825	10-12″-16-5″-4-3 pdr.
Wyoming and Arkansas	1909	562′	26000	12-12″-21-5″-4-3 pdr.
New York and Texas	1910	573′	27000	10-14″-21-5″-4-3 pdr.
Oklahoma and Nevada	1911	583′	27500	10-14″-21-5″-4-3 pdr.
Pennsylvania	1912	608′	31400	12-14″-22-5″-4-3″ AA 4-3 pdr.
New Mexico, Mississippi, Idaho	1914	624′	32000	12-14″-22-5″-4-3″ AA 4-3 pdr.
Tennessee and California	1915	624′	32300	12-14″-14-5″-4-3″ AA 4-6 pdr.
Colorado, Maryland, West Virginia, Washington	1916	624′	32600	8-16″-14-5″-4-3″ AA 4-6 pdr.
South Dakota, Indiana, Montana, North Carolina, Iowa, Massachusetts	1916–1917 1918	684′	43200	12-16″-16-6″-4-3″ AA 4-6 pdr.

NUMBER OF CONDITIONS IMPOSED BY A SET OF ORDER NUMBERS

By J. C. Fields, Ph.D., F.R.S.

§ 1. Let

1. $$f(z, u)=0$$

be an equation in which $f(z, u)$ is a polynomial in u of degree n with coefficients which are rational functions of z—or more generally series in powers of z, involving only a finite number of negative exponents. The branches of the function u corresponding to the value $z=0$ group themselves into a number r of cycles of orders $\nu_1, \nu_2, \ldots, \nu_r$ respectively. Adjointness relative to this value of the variable z is defined by a set of order numbers $\mu_1-1+1/\nu_1, \ldots, \mu_r-1+1/\nu_r$ where $\mu_1, \ldots, \mu_r$ are the order numbers of the function $f'_u(z, u)$ for $z=0$. Two sets of order numbers $\tau_1, \ldots, \tau_r$ and $\bar{\tau}_1, \ldots, \bar{\tau}_r$ are said to be complementary adjoint when we have

2. $$\tau_s+\bar{\tau}_s=\mu_s-1+1/\nu_s;\ s=1, 2, \ldots, r.$$

On designating by $z^{-i}\big((z, u)\big)_\tau$ the general function of (z, u) of rational character for the value $z=0$, which is conditioned by the order numbers $\tau_1, \ldots, \tau_r$, the vanishing of the principal residue relative to this value of z in the product

3. $$z^{-i}\big((z, u)\big)_\tau\psi(z, u)$$

is, as we know,* the necessary and sufficient condition in order that $\psi(z, u)$ may have the order numbers $\bar{\tau}_1, \ldots, \bar{\tau}_r$.

We shall now consider a product

4. $$\sum_{t=1}^{n}\sum_{r=-i+1}^{i}\beta_{-r,\,n-t}z^{-r}u^{n-t}\sum_{t=1}^{n}\sum_{r=-i+1}^{i}\alpha_{r-1,\,t-1}z^{r-1}u^{t-1}$$

in which the two factors are of identically the same form so long as the coefficients $\beta_{-r,\,n-t}$ and $\alpha_{r-1,\,t-1}$ are all arbitrary. Holding the $2ni$ coefficients $\beta_{-r,\,n-t}$ all arbitrary and equating to 0 the principal residue in the product, it is readily seen that we make the $2ni$ coefficients $\alpha_{r-1,\,t-1}$ all vanish. For if the second factor in (4.) is not identically 0 we shall

*"On the foundations of the theory of algebraic functions of one variable," Phil. Trans. Roy. Soc. Series A, Vol. 212, p. 345.

have included under it a specific function of the form of the second factor in the product

$$5. \qquad \beta_{-\rho,\, n-\sigma} z^{-\rho} u^{n-\sigma} \sum_{t=1}^{\sigma} \sum_{r=-i+1}^{i} \alpha'_{r-1,\, t-1} z^{r-1} u^{t-1}$$

where $u^{\sigma-1}$ is the highest power of u which presents itself under the double summation and where we have a coefficient $\alpha'_{\rho-1,\,\sigma-1} \neq 0$. The principal residue in the product (5) is $\beta_{-\rho,\, n-\sigma} \alpha'_{\rho-1,\,\sigma-1}$, which is not identically 0. If, then, the principal coefficient in the product (4) is identically 0 for arbitrary values of the $2ni$ coefficients $\beta_{-r,\, n-t}$ the $2ni$ coefficients $\alpha_{r-1,\, t-1}$ must all vanish. It is immediately apparent that on equating to 0 turn about the principal residue relative to $z=0$ in the product of the second factor in (4) by each of any $2ni$ specific linearly independent functions contained under the form of the first factor in (4) we impose on the $2ni$ coefficients $\alpha_{r-1,\, t-1}$ as many linearly independent conditions. If, therefore, we condition the first factor in (4) by the order numbers $\tau_1, \ldots, \tau_r$, thus imposing λ conditions on the coefficients $\beta_{-r,\, n-t}$, and thereafter equate to 0 the principal residue in the product, we impose precisely $2ni-\lambda$ conditions on the coefficients $\alpha_{r-1,\, t-1}$.

We shall now assume for the moment that the equation (1) is of integral character relative to the value $z=0$. It is then evident that on equating to 0 the principal residue relative to $z=0$ in the product

$$6. \qquad z^{-i}\big((z,\, u)\big)_r \sum_{t=1,\, r=-i+1}^{n} \sum^{i} \alpha_{r-1,\, t-1} z^{r-1} u^{t-1}$$

we impose on the coefficients $\alpha_{r-1,\, t-1}$ the $2ni-\lambda$ conditions referred to above, for terms in the first factor of (6) involving z to as high a power as z^i cannot make any contribution to the principal residue in the product. Assuming i to be taken sufficiently great the $2ni-\lambda$ conditions here in question are precisely those conditions which are requisite in order that the second factor in (6) may have the order numbers $\bar{\tau}_1, \ldots, \bar{\tau}_r$ for the value $z=0$. These, then, are also the conditions which are imposed on the general function of the form $z^{-i}\big((z,\, u)\big)$ by the order numbers $\bar{\tau}_1, \ldots, \bar{\tau}_r$. The numbers of the conditions imposed on the general function of the form $z^{-i}\big((z,\, u)\big)$ by the sets of order numbers $\tau_1, \ldots, \tau_r$ and $\bar{\tau}_1, \ldots, \bar{\tau}_r$ respectively are therefore λ and $2ni-\lambda$. The difference between the numbers of these conditions is $2\lambda-2ni$, and this difference is readily seen to be also $\sum_{s=1}^{r} (\tau_s - \bar{\tau}_s)\nu_s$. For if $t_1, \ldots, t_r$ be a set of coincidences on a lower level than either of the sets $\tau_1, \ldots, \tau_r$ or $\bar{\tau}_1, \ldots, \bar{\tau}_r$ and if i be chosen sufficiently great we

see that the difference in the numbers of the conditions imposed on the general function of the form $z^{-i}\big((z, u)\big)$ by the sets $\tau_1, \ldots, \tau_r$ and $t_1, \ldots, t_r$ is $\sum_{s=1}^{r}(\tau_s - t_s)\nu_s$ while $\sum_{s=1}^{r}(\bar{\tau}_s - t_s)\nu_s$ is the difference in the numbers of the conditions imposed on the general function in question by the sets $\bar{\tau}_1, \ldots, \bar{\tau}_r$ and $t_1, \ldots, t_r$. It follows that the difference in the numbers of the conditions imposed on the general function of the form $z^{-i}\big((z, u)\big)$ by the sets $\tau_1, \ldots, \tau_r$ and $\bar{\tau}_1, \ldots, \bar{\tau}_r$ is $\sum_{s=1}^{r}(\tau_s - \bar{\tau}_s)\nu_s$. We consequently have $2\lambda - 2ni = \sum_{s=1}^{r}(\tau_s - \bar{\tau}_s)\nu_s$, whence

$$7. \qquad \lambda = ni + \tfrac{1}{2}\sum_{s=1}^{r}(\tau_s - \bar{\tau}_s)\nu_s.$$

Combining (7) with (2) we evidently have

$$8. \qquad \lambda = ni + \sum_{s=1}^{r}\tau_s\nu_s - \tfrac{1}{2}\sum_{s=1}^{r}(\mu_s - 1 + 1/\nu_s)\nu_s.$$

In deriving the last two formulae we have assumed the equation (1) to be integral. Supposing this not to be the case we can choose an integer j such that on writing $z^j u = v$ equation (1) transforms into an integral equation $F(z, v) = 0$. Here $F(z, v) = z^{nj} f(z, u)$ and we have $F'_v(z, v) = z^{(n-1)j} f'_u(z, u)$. On designating the order numbers of $F'_v(z, v)$ for the r cycles corresponding to the value $z = 0$ by the notation $\mu'_1, \ldots, \mu'_r$ we evidently have $\mu'_s = (n-1)\,j + \mu_s$; $s = 1, \ldots, r$. For the number λ' of the conditions imposed on the general function of the form $z^{-i}\big((z, v)\big)$ by the set of order numbers $\tau_1, \ldots, \tau_r$ we can, in analogy with formula (8), then write

$$\lambda' = ni + \sum_{s=1}^{r}\tau_s\nu_s - \tfrac{1}{2}\sum_{s=1}^{r}(\mu'_s - 1 + 1/\nu_s)\nu_s,$$

and from this we derive

$$9. \qquad \lambda' + \tfrac{1}{2}n(n-1)\,j = ni + \sum_{s=1}^{r}\tau_s\nu_s - \tfrac{1}{2}\sum_{s=1}^{r}(\mu_s - 1 + 1/\nu_s)\nu_s.$$

The general form $z^{-i}\big((z, v)\big)$, expressed in terms of z and u, may be written

$$10. \qquad z^{-i}\big((z, v)\big) = z^{-i+(n-1)j}P_{n-1}u^{n-1} + \ldots + z^{-i+j}P_1 u + z^{-i}P_0.$$

where $P_{n-1}, \ldots, P_0$ are series in power of z not involving negative exponents. This form, however, is included under the general form $z^{-i}\big((z,u)\big)$ and lacks just $(n-1)\,j + (n-2)j + \ldots + 2j + j$ of the terms included under the latter form. The general form (10) is then derived from the

general form $z^{-i}\big((z, u)\big)$ on equating $\frac{1}{2}n(n-1)j$ coefficients in the latter form to 0. The number of the conditions imposed on the general function of the form $z^{-i}\big((z, u)\big)$ by the set of order numbers $\tau_1, \ldots, \tau_r$ is, therefore, $\lambda'+\frac{1}{2}n(n-1)j$. From (9) then we see that the number of the conditions imposed on the general function of the form $z^{-i}\big((z, u)\big)$ by the set of order numbers $\tau_1, \ldots, \tau_r$ is given by formula (8) whether the equation (1) is integral or not. The formula (7) holds good at the same time, too, as we see on combining (8) with (2).

Formulae (7) and (8) have been obtained on the assumption that $-i$ has been taken sufficiently small. There is a least number $-i'$ such that terms involving the power $z^{-i'}$ may actually present themselves in a rational function conditioned by the set of order numbers $\tau_1, \ldots, \tau_r$. It is evident that our formulae hold good so long as we have taken $-i \geqq -i'$.

If for $\tau_1, \ldots, \tau_r$ we take the order numbers defining adjointness for the value $z=0$, formulae (7) and (8) evidently give us the expression

$$ni+\tfrac{1}{2}\sum_{s=1}^{r}(\mu_s-1+1/\nu_s)\nu_s$$

for the number of the conditions imposed by adjointness relative to the value $z=0$ on the general function of the form $z^{-i}\big((z, u)\big)$, while the same formulae give us the expression

$$ni-\tfrac{1}{2}\sum_{s=1}^{r}(\mu_s-1+1/\nu_s)\nu_s$$

for the number of the conditions imposed on the general function of this form by the 0-set of order numbers corresponding to the value $z=0$.

The formulae obtained in the preceding can also be derived directly in the case where the equation (1) is nonintegral. This we have already shown elsewhere. We shall however here indicate it in abbreviated form. We shall for the moment suppose the coefficients $\beta_{-r, n-t}$ and $a_{r-1, t-1}$ in the product (4) to be arbitrary for $r=-j, \ldots, -i+1$, the remaining coefficients being 0. If we hold the $n(i-j)$ coefficients $\beta_{-r, n-t}$ here in question arbitrary and equate to 0 the principal residue in the product the $n(i-j)$ coefficients $a_{r-1, t-1}$, in which r has one of the values $-j, \ldots, -i+1$, evidently all vanish. That is to say we subject these $n(i-j)$ coefficients to as many linearly independent conditions.

In the case then where the $2ni$ coefficients $a_{r-1, t-1}$ are assumed to be arbitrary to begin with, as also the $n(i-j)$ coefficients $\beta_{-r, n-t}$ for which r has one of the values $-j, \ldots, -i+1$, whatever restrictions may be placed on the other coefficients $\beta_{-r, n-t}$, it is evident that among the conditions imposed on the coefficients $a_{r-1, t-1}$ when we equate to 0 the principal residue in the product (4), are $n(i-j)$ conditions which are linearly

independent in the $n(i-j)$ coefficients $a_{r-1,\,t-1}$ in which r has one of the values $-j, \ldots, -i+1$. All the other conditions may be regarded as imposed on the coefficients $a_{r-1,\,t-1}$ in which $r > -j$. It is plain then also that the addition to the first factor in (4) of any term involving a power of z higher than z^{i-1} can introduce no further condition on the coefficients $a_{r-1,\,t-1}$ when we equate to 0 the principal residue in the product, the integer i being chosen sufficiently great, for the presence of such term could impose no conditions on coefficients $a_{r-1,\,t-1}$ in which $r > -j$. The $2ni-\lambda$ conditions imposed on the coefficients $a_{r-1,\,t-1}$ on equating to 0 the principal residue in the product (4) therefore constitute the total conditions requisite in order that the second factor in (4) may have the order numbers $\bar{\tau}_1, \ldots, \bar{\tau}_r$. The formula for λ then follows as before.

In what precedes there is nothing essentially new. There is simply some slight modification and abbreviation of what the writer has already given elsewhere. When however a fundamental formula like formula (8) has been obtained in one way it is usually not difficult to arrive at the result in a multiplicity of other ways. Knowing the formula in advance we have our orientation and it is only necessary to consider it in its various connections and to note its bearing on the elements involved in order to anticipate a line of proof depending on these elements. We shall here adjoin a couple of proofs so obtained.

§ **2.** We know from elementary considerations that the number of the conditions imposed on a rational function of (z, u) of sufficient generality by a set of order numbers corresponding to the value $z=0$ is given by the sum of these order numbers plus a fixed number which is independent of the values of the order numbers. In particular the number of the conditions imposed on the general function of the form $z^{-i}((z, u))$ by the set of order numbers $\tau_1, \ldots, \tau_r$ is $ni + \sum_{s=1}^{r} \tau_s \nu_s - A$ where A is a definite number the determination of which would give us formula (8). To determine A it will then suffice to determine the number of the conditions imposed on the general function of the form $z^{-i}((z, u))$ for a sufficiently great value of i by a specific set of order numbers.

To abbreviate matters we shall suppose as before that the equation (1) is integral. The general rational function which is adjoint relatively to the value $z=0$ is included under the form $((z, u))$. What is the number of the conditions imposed on this general form by the set of adjoint order numbers $\mu_1-1+1/\nu_1, \ldots, \mu_r-1+1/\nu_r$?

We shall employ the notations $z^{-i}((z, u))_0$ and $((z, u))_a$ to designate respectively the general rational function of integral algebraic character

for the value $z=0$ and the general rational function which is adjoint relatively to this value of the variable z. The number of arbitrary constants involved in the expression of the principal part of the former function we shall indicate by λ.

A complete basis for the representation of the functions included under $((z,u))_a$ we shall suppose to be constituted by n functions

11. $$z^{\kappa_n-1}R_{n-1}(z,u),\ z^{\kappa_n-2}R_{n-2}(z,u),\ \ldots,\ z^{\kappa_0}R_0(z,u)$$

whose degrees in u are $n-1, n-2, \ldots, 0$ respectively. The functions $R_{n-1}, R_{n-2}, \ldots, R_0$ are understood to be integral in z as well as in u. Also it is readily seen that we may assume the coefficient of the highest power of u in each of them to be 1. We have $R_0(z,u)=1$ and κ_0 has for value the greatest of the integers $[\mu_1], [\mu_2], \ldots, [\mu_r]$. We may, if we will, assume $R_{n-1}(z,u)$ to have order numbers, relative to $z=0$, none of which is less than the greatest of the numbers $\mu_1, \mu_2, \ldots, \mu_r$. Evidently $\kappa_{n-1}=0$.

A complete basis for the representation of the functions included under $z^{-i}((z,u))_0$ we shall indicate by the notation

12. $$z^{-\lambda_{n-1}}\rho_{n-1}(z,u),\ z^{-\lambda_{n-2}}\rho_{n-2}(z,u),\ \ldots,\ z^{-\lambda_0}\rho_0(z,u),$$

the degrees in u of these n functions being $n-1, n-2, \ldots, 0$ respectively. The functions $\rho_{n-1}, \rho_{n-2}, \ldots, \rho_0$ are integral in z as well as in u. We may if we will suppose them polynomial in z and the same is true of the functions $R_{n-1}, R_{n-2}, \ldots, R_0$. The coefficient of the highest power of u in each of the functions ρ is taken to be 1. We have $\rho_0(z,u)=1$, $\lambda_0=0$. Also λ_{n-1} is equal to the greatest of the integers $[\mu_1], \ldots, [\mu_r]$.

We may write

13.
$$((z,u))_a=\sum_{s=0}^{n-1} z^{\kappa_s}Q_sR_s,\quad ((z,u))=\sum_{s=0}^{n-1}Q_sR_s,\quad z^{-i}((z,u))_0=\sum_{s=0}^{n-1}z^{-\lambda_s}Q_s\rho_s,$$

where $Q_0, Q_1, \ldots, Q_{n-1}$ are employed to indicate arbitrary series in powers of z which involve no negative exponents. Evidently $i=\lambda_{n-1}$. We may take $\rho_{n-1}=R_{n-1}$ and in the case where our equation $f(z,u)=0$ is constituted by one cycle only relative to the value $z=0$ it is readily seen that we may take $\rho_s=R_s$, $s=0, 1, \ldots, n-1$. In this case we may evidently select each function $\rho_s=R_s$ so that its single order number relative to $z=0$ is as great as is compatible with its degree in u, the coefficient of the highest power of u being 1.

The number of arbitrary constants which present themselves in the principal part of $z^{-i}((z,u))$ is $\lambda=\sum_{s=0}^{n-1}\lambda_s$. This is the number of the conditions which reduce $z^{-i}((z,u))_0$ to the form $((z,u))$. Also the

number of the conditions which reduce $((z, u))$ to the form $((z, u))_a$ is $\kappa = \sum_{s=0}^{n-1} \kappa_s$. We have $\lambda + \kappa = \sum_{s=1}^{r} (\mu_s - 1 + 1(\nu_s)\nu_s$ since this, as we know, is the number of the conditions which reduce $z^{-i}((z, u))_0$ to the adjoint form $((z, u))_a$.

The products

$$14. \qquad z^{\kappa_n - s - \lambda_s - 1} R_{n-s} \rho_{s-1} \; ; \; s = 1, 2, \ldots n$$

are all adjoint relatively to $z = 0$. Also the products $R_{n-s}\rho_{s-1}$ are all of degree $n-1$ in u with 1 for principal coefficient. The order numbers of these latter products for $z = 0$ cannot therefore be simultaneously greater than $\mu_1, \ldots, \mu_r$. It follows that none of the differences $\kappa_{n-s} - \lambda_{s-1}$ can be negative. As a consequence we have $\kappa \overline{\overline{>}} \lambda$.

We impose on the coefficients of the function $((z, u))$ the conditions requisite to adjointness on equating to 0 the principal residue relative to $z = 0$ in the product

$$z^{-i}((z, u))_0 \, ((z, u)).$$

Since λ is the number of the arbitrary constants in the principal part of $z^{-i}((z, u))_0$ the number of the conditions requisite to adjointness on the part of $((z, u))$ is $\overline{\overline{<}} \lambda$. But the number of these conditions is κ. We therefore have $\kappa \overline{\overline{<}} \lambda$. Since it has been ptoved that $\kappa \overline{\overline{>}} \lambda$ we derive $\kappa = \lambda$. Now the number of the conditions which reduce the form $z^{-i}((z, u))_0$ to the form $((z, u))_a$ is $\lambda + \kappa = \sum_{s=1}^{r} (\mu_s - 1 + 1/\nu_s)\nu_s$. We consequently have

$$15. \qquad \lambda = \kappa = \tfrac{1}{2} \sum_{s=1}^{r} (\mu_s - 1 + 1/\nu_s)\nu_s.$$

§ 3. From the equality $\kappa = \lambda$ and the inequalities $\kappa_{n-s} \overline{\overline{>}} \lambda_{s-1}$, obtained in what precedes, we derive $\kappa_{n-s} = \lambda_{s-1}$; $s = 1, 2, \ldots, n$. It would suggest itself to arrive at our formula by proving these equalities directly. We shall not here attempt the detail involved in the consideration of the general case but shall for the moment restrict ourselves to the special case where $f(z, u) = 0$ presents only one cycle corresponding to the value $z = 0$. The order number of $f'_u(z, u)$ we shall designate by μ. A polynomial in u with coefficients of rational character relative to the value $z = 0$, must, if it is adjoint for this value of the variable z, be of integral character relative to z. Also it must be divisible by z if its order number is greater than μ.

In the products (14) for the case here under consideration we may, as has already been pointed out, assume $\rho_s = R_s$; $s = 0, 1, \ldots, n-1$. As has already been noted, we may also suppose these functions to have

the maximum order numbers consistent with the limitations imposed on their forms. In (14) we shall assume that the functions R_{n-s} and $\rho_{s-1} = R_{s-1}$ have maximum order numbers. These order numbers we shall designate as a_{n-s} and a_{s-1} respectively. Since the product $R^{n-s}\rho_{s-1}$ is of degree $n-1$ in u with 1 for the coefficient of u^{n-1} it is evident that $a_{n-s}+a_{s-1}$ cannot be greater than μ. We shall here assume $a_{n-s}+a_{s-1}=\mu$ and shall justify our assumption later on in a supplemental lemma.

From the nature of the basis functions in (11) it is plain that we must here have $\mu-1+1/\nu \overline{\overline{<}} \kappa_{n-s}+a_{n-s} < \mu+1/\nu$ whence $a_{s-1}-1+1/\nu \overline{\overline{<}} \kappa_{n-s} < a_{s-1}+1/\nu$ and therefore $a_{s-1}-1 < \kappa_{n-s} \overline{\overline{<}} a_{s-1}$. From the nature of the basis functions in (12) we derive immediately $a_{s-1}-1 < \lambda_{s-1} \overline{\overline{<}} a_{s-1}$. From the foregoing inequalities we conclude $\kappa_{n-s}=\lambda_{s-1}$; $s=1, 2, \ldots n$, and consequently $\kappa=\lambda$. From $\kappa+\lambda=(\mu-1+1/\nu)\nu$ then follows

16. $$\lambda=\kappa=\tfrac{1}{2}(\mu-1+1/\nu)\nu,$$

the special case of formula (15) when equation (1) consists of a single cycle of order $n=\nu$ for the value $z=0$. For the number of the conditions imposed by an adjoint order number τ on the general polynomial of degree $n-1=\nu-1$ in u, with coefficients of integral rational character relative to the value $z=0$, we immediately derive the expression

17. $$\tau\nu-\tfrac{1}{2}(\mu-1+1/\nu)\nu.$$

To complete the above proof we have to establish the supplemental lemma $a_{n-s}+a_{s-1}=\mu$. With this end in view we shall proceed to construct a polynomial of degree $n-1$ in u with coefficients of integral rational character in z, the coefficient of u^{n-1} being 1, the order number of the polynomial for $z=0$ being μ.

Let us consider the successive terms in one of the branches $u-P=0$ of the cycle of order ν with which we are here concerned. The full order ν of the cycle to which the branch belongs may not immediately declare itself. The cyclical characters successively presenting themselves we shall designate by $1, \nu', \nu'', \ldots, \nu^{(t)}, \nu$ where evidently each element in the succession is a factor of the one which follows. We shall write $\nu=\lambda^{(t)}\nu^{(t)}$, $\nu^{(t)}=\lambda^{(t-1)}\nu^{(t-1)}$, $\ldots$, $\nu''=\lambda'\nu'$.

Suppose $\overline{P}_1, \overline{P}_2, \ldots, \overline{P}_{\nu(t)}$ to be portions of $\nu(t)$ series $P_1, P_2, \ldots, P_{\nu(t)}$ these part series characterizing a cycle of order $\nu^{(t)}$. Furthermore suppose these partial series to contain every term of the respective series $P_1, P_2, \ldots, P_{\nu(t)}$ up to and including the last terms in these series antecedent to the first terms which determine the series as belonging to

a cycle of order ν. The product $(u-\overline{P}_1)\,(u-\overline{P}_2)\ldots(u-\overline{P}_{\nu^{(t)}})$ we shall call a truncated function of cyclical character $\nu^{(t)}$.

We shall now build up a polynomial of degree $n-1$ in u constructing it as a product of cyclical truncated functions, as follows. We first multiply together $\lambda^{(t)}-1$ of the truncated functions referred to above as of cyclical character $\nu^{(t)}$. This leaves a factor of degree $\nu^{(t)}-1$ still to provide for. From one of our truncated functions of cyclical character $\nu^{(t)}$ truncate $\lambda^{(t-1)}$ identical functions of cyclical character $\nu^{(t-1)}$. By $\lambda^{(t-1)}-1$ of these functions multiply the product of $\lambda^{(t)}-1$ functions of cyclical character $\nu^{(t)}$ already formed. This leaves a factor of degree $\nu^{(t-1)}-1$ still to provide for. So proceeding we ultimately construct a product $R(z, u)$ of degree $n-1$ in u, made up of $\lambda^{(t)}-1$ identical factors of degree $\nu,^{(t)}$ of $\lambda^{(t-1)}-1$ identica factors of degree $\nu,^{(t-1)}\ldots$, of $\lambda'-1$ identical factors of degree ν' and of $\nu'-1$ identical factors of degree 1 in u. The order number of this product is evidently μ.

Out of the factors of $R(z,u)$ we now construct as products two functions $R_{n-s}\,(z,u)$ and $R_{s-1}\,(z,u)$ the degrees of which in u are indicated by their suffixes. This can be done in one way only. For in fitting into R_{n-s} and R_{s-1} the maximum numbers of factors of cyclical character $\nu^{(t)}$ permitted by the degrees of these functions in u we just dispose of the $\lambda^{(t)}-1$ factors of this cyclical character contained in $R(z,u)$. There remain to be fitted into R_{n-s} and R_{s-1} factors whose degrees in the aggregate are $\nu^{(t)}-1$. Just as we distributed between R_{n-s} and R_{s-1} the $\lambda^{(t)}-1$ factors of cyclical character $\nu^{(t)}$ contained in $R(z,u)$ so now we further distribute between R_{n-s} and R_{s-1} the $\lambda^{(t-1)}-1$ factors of $R(z,u)$ of cyc ical character $\nu^{(t-1)}$ which evidently can also be done in one and only one way. So proceeding it is evident that we can factor $R(z,u)$ uniquely in the form $R(z,u)=R_{n-s}(z,u)R_{s-1}\,(z,u)$, the degrees in u of the factors being indicated by the suffixes. The fact that we can split $R(z,u)$ into two such factors suffices to establish the lemma $\alpha_{n-s}+\alpha_{s-1}=\mu$ and the proof of formula (16) is therewith complete.

§4. Having obtained the formula (16) with reference to a single cycle we can deduce the more general formula (15) in various ways.

Representing $f(z,u)$ as the product of its cyclical factors we write

$$f(z,u)=f_1(z,u)\,f_2(z,u)\ldots f_r(z,u)$$

where $\nu_1, \nu_2, \ldots, \nu_r$ are the degrees in u of the respective factors. The sum of the orders of coincidence of one branch of the equation $f_s(z,u)=0$ with the remaining ν_s-1 branches we shall indicate by μ_s'. Adjointness relative to this cyclical equation for the value $z=0$ will then be defined by the order number $\mu_s'-1+1/\nu_s$.

In the case of any polynomial $H(z, u)$ in u with coefficients of rational character in z we can write

$$18. \quad H(z,u) \equiv \sum_{s=1}^{r} G_s(z,u) f_1(z,u) \ldots f_{s-1}(z,u) f_{s+1}(z,u) \ldots f_r(z,u), \mod f(z,u),$$

where $G_1(z,u), \ldots, G_r(z,u)$ are polynomials in u of degrees $\nu_1-1, \ldots, \nu_r-1$ respectively. The values of the function $H(z,u)$ are, as we know, given by the summation on the right-hand side of the congruence when u satisfies the equation $f(z,u)=0$.

In the case of the general function $((z,u))$ we can, in analogous manner, evidently write

$$19. \quad ((z,u)) \equiv \sum_{s=1}^{t} g_s(z,u) f_1(z,u) \ldots f_{s-1}(z,u) f_{s+1}(z,u) \ldots f_t(z,u), \mod f_1(z,u) \ldots f_t(z,u),$$

where $g_1(z.u), \ldots, g_t(z,u)$ are polynomials in u of the respective degrees $\nu_1-1, \ldots, \nu_t-1$ with coefficients which are of rational character relatively to the value $z=0$.

Let us now assume that we are imposing on the coefficients of the general function $((z,u))$ the conditions requisite to adjointness relative to the equation $f(z,u)=0$, not simultaneously, but successively for the branches of the several cyclical equations $f_1(z,u)=0$, $f_2(z,u)=0, \ldots, f_r(z,u)=0$. Suppose we have imposed these adjoint conditions successively for the branches of the cyclical equations $f_1(z,u)=0, \ldots, f_{t-1}(z,u)=0$. Let us consider the congruence (19). By virtue of the orders of coincidence in question it is evident that among other restrictions on the $t-1$ polynomials $g_1(z,u), \ldots, g_{t-1}(z,u)$ they will have coefficients which are of integral character for the value $z=0$. Because of the integral character of $((z,u))$ it will then follow from the congruence that the coefficients of the polynomial $g_t(z,u)$ must also be of integral character relative to $z=0$. It is also evident that the orders of coincidence in question impose no further conditions on the polynomial $g_t(z,u)$. On considering the tth element in the summation on the right-hand side of the congruence we see that with the imposition on the function $((z,u))$ of the adjoint orders of coincidence corresponding to the branches of the $t-1$ cyclical equations $f_1(z,u)=0, \ldots, f_{t-1}(z,u)=0$ we have at the same time imposed on the function an order of coincidence with the branches of the cyclical equation $f_t(z,u)=0$ which is equal to the order of coincidence of the product $f_1(z,u) \ldots f_{t-1}(z,u)$ with one of these branches.

Let us now increase the orders of coincidence of the function $((z, u))$ with the branches of the equation $f_t(z,u)=0$ to what is requisite for adjointness relative to the equation $f(z, u) = 0$ on the part of these branches. This means imposing on the function $g_t(z,u)$ the order of coincidence $\mu_t-1+1/\nu_t-\bar{\mu}_t$ relative to a branch of the cyclical equation $f_t(z, u)=0$ where, for the moment, we employ the notation $\bar{\mu}_t$ to designate the order of coincidence of the product $f_1(z, u) \ldots f_{t-1}(z, u)$ with a branch of the equation $f_t(z, u)=0$. The number of the conditions so imposed on the coefficients of the function $g_t(z, u)$, and therewith the number of the additional conditions imposed on the coefficients of the function $((z, u))$ is then, in accord with formula (17), given by the expression

$$(\mu_t-1+1/\nu_t-\bar{\mu}_t)\nu_t-\tfrac{1}{2}(\mu_t'-1+1/\nu_t)\nu_t.$$

The total number of the conditions imposed on the general function $((z, u))$ by adjointness relative to the value $z=0$ is then given by the sum

$$20. \qquad \sum_{t=1}^{r}\left\{(\mu_t-1+1/\nu_t-\bar{\mu}_t)\nu_t-\tfrac{1}{2}(\mu_t'-1+1/\nu_t)\nu_t\right\}.$$

Now $\sum_{t=1}^{r}\bar{\mu}_t\nu_t$ is evidently equal to half the aggregate of all those numbers each of which is the sum of the orders of coincidence of a branch with the branches of all the cycles other than its own. The sum $\sum_{t=1}^{r}\bar{\mu}_t\nu_t+\frac{1}{2}\sum_{t=1}^{r}\mu_t'\nu_t$ is then equal to half the aggregate of all those numbers each of which is the sum of the orders of coincidence of a branch with the remaining $n-1$ branches of the equation $f(z,u)=0$. The sum in question is then equal to $\frac{1}{2}\sum_{t=1}^{r}\mu_t\nu_t$. The expression given in (20) for the number of the conditions imposed on the coefficients of the general function $((z, u))$ by adjointness relative to the equation $f(z, u)=0$ for the value $z=0$ can therefore be written in the form

$$\tfrac{1}{2}\sum_{t=1}^{r}(\mu_t-1+1/\nu_t)\nu_t.$$

§ **5**. We shall now develop another method for reaching our results in the general case, on starting out from the formulae (16) and (17) obtained for the case of a single cycle. In connection with the proof of these formulae we had occasion to construct a function $R(z, u)$ synthetically as a product of a number of cyclical factors. The extension of these formulae to the general case we shall here effect through an analysis of the conditions under which factorization of the general function

$((z, u))$ takes place. As before we shall understand that this function is of degree $n-1$ in u and $f(z,u)$ we shall assume to be a product of r cyclical factors $f_1(z,u)$, . . . , $f_r(z, u)$.

Let us consider a set of order numbers $\tau_1, \ldots, \tau_r$ which are adjoint but not simultaneously greater than the numbers $\mu_1, \ldots, \mu_r$. We shall suppose $\tau_1, \ldots, \tau_{r-1}$ to have values as great as we will and τ_r will then have one of the values $\mu_r-1+1/\nu_r, \ldots, \mu_r$. These order numbers we propose to impose successively in the order $\tau_1, \tau_2, \ldots, \tau_r$ on the function $((z,u))$. They will not require the principal coefficient to be divisible by z and they will evidently impose the same number of conditions on the general function $((z,u))$ which is unrestricted to begin with and on the general function after we have assigned a specific form to the principal coefficient so long as the form in question is not divisible by z. We shall then from this on assume that the otherwise general function $((z,u))$ has 1 for its principal coefficient.

In accord with formula (17) the order number τ_1 imposes $\tau_1\nu_1-\frac{1}{2}(\mu_1'-1+1/\nu_1)\nu_1$ conditions on the coefficients of the general polynomial of degree ν_1-1 in u with coefficients of integral rational character for the value $z=0$. This then is also the number of the conditions imposed by the order number τ_1 on the general polynomial of degree $n-1 \overline{\overline{>}} \nu_1-1$ in u, with coefficients of integral rational character relative to the value $z=0$, and therewith the number of the conditions imposed by this order number on the function $((z,u))$ here in question. We may now suppose this function to be represented as a product $((z,u))_{\nu_1}\,((z,u))_{n-\nu_1-1}$ where the suffixes indicate the degrees of the respective factors in u, the coefficient of the highest power of u being 1 in the case of each factor. The two factors here in question are not uniquely characterized. If we suppose the first factor to contribute the total order number τ_1 and the second factor to be arbitrary, save for the coefficient of $u^{n-\nu_1-1}$ the product is included under the function $((z,u))$ conditioned by the order number τ_1. Included under the function so conditioned however are also products in which the first factor does not contribute the total order number τ_1. In any case we may assume τ_1 to be so great that the first factor must coincide with $f_1(z,u)$ out to such point, and as far beyond as we will, that its orders of coincidence with the branches of the equations $f_2(z,u)=0, \ldots, f_r(z,u)=0$ are the same as those of the function $f_1(z,u)$ with these branches.

We shall for the moment employ the notation $\bar{\mu}_{s,t}$ to designate the order of coincidence of a branch of the tth cycle with the sth cyclical factor $f_s(z,u)$ of $f(z,u)$. Let us now split off from $((z,u))_{n-\nu_1-1}$ a factor $((z,u))_{\nu_2}$ of degree ν_2 in u on imposing on the former function the order

number τ_2 less $\bar{\mu}_{1,2}$, the order number of the factor $((z,u))_{\nu_1}$ with a branch of the second cycle. We thus impose on the function $((z,u))$ further conditions $(\tau_2-\bar{\mu}_{1,2})\nu_2-\frac{1}{2}(\mu_2'-1+1/\nu_2)\nu_2$ in number because of the alternative arbitrary character of the factor $((z,u))_{n-\nu_1-1}$.

We now have

21. $$((z,u))=((z,u))_{\nu_1}((z,u))_{\nu_2}((z,u))_{n-\nu_1-\nu_2-1}.$$

Here we may assume $((z,u))_{\nu_2}$ to coincide with $f_2(z,u)$ out to a point such that its orders of coincidence with the branches of the cycles other than the second are the same as the orders of coincidence of $f_2(z,u)$ with these branches. Also the above factorization does not impose on the function $((z,u))$ an order number for the 1st cycle which is greater than τ_1, because of the alternative possibility referred to above in which the factor $((z,u))_{\nu_1}$ does not contribute the total order number τ_1.

Continuing the process of factorization by which we arrived at (21) the splitting of a factor $((z,u))_{\nu_3}$ from $((z,u))_{n-\nu_1-\nu_2-1}$ imposes on the coefficients of the function $((z,u))$ additional conditions $(\tau_3-\bar{\mu}_{1,3}-\bar{\mu}_{2,3})\nu_3-\frac{1}{2}(\mu_3'-1+1/\nu_3)\nu_3$ in number. So proceeding we ultimately arrive at a factorization of the type

$$((z,\mu))=((z,u))_{\nu_1}((z,u))_{\nu_2}\cdots((z,u))_{\nu_r-1}((z,u))_{\nu_r-1}$$

and determine thereby for the number of the conditions imposed on the function $((z,u))$ by the order numbers $\tau_1,\ldots,\tau_r$ the expression

$$\sum_{t=1}^{r}\tau_t\nu_t-\sum_{t=2}^{r}\sum_{s=1}^{t-1}\bar{\mu}_{s,t}\nu_t-\frac{1}{2}\sum_{t=1}^{r}(\mu_t'-1+1/\nu_t)\nu_t$$

which is evidently equal to

$$\sum_{t=1}^{r}\tau_t\nu_t-\frac{1}{2}\sum_{t=1}^{r}(\mu_t-1+1/\nu_t)\nu_t.$$

In what precedes we have not gone into detail as much as we might have done. We have not followed all the leads which presented themselves. We have by no means exhausted all the lines of proof which were suggested by the context. What we have done is to illustrate in a humble way what the writer recently heard called the method of "nosing along" by one who in reading a mathematical book had noted therein the employment of this method and had accordingly decided against its scientific merits because he had failed to grasp the fact that this is the one and only method for the systematic uncovering of truth vouchsafed to man and compatible with his psychology.

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